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Science & Technology Trends

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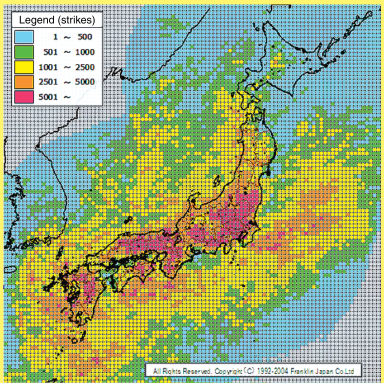


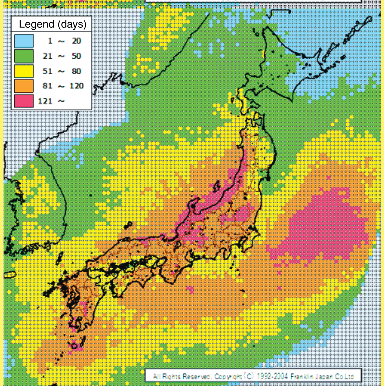


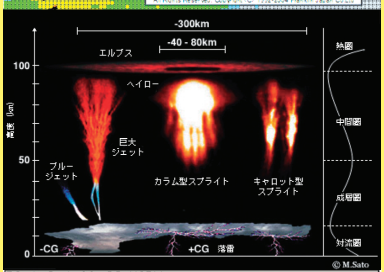


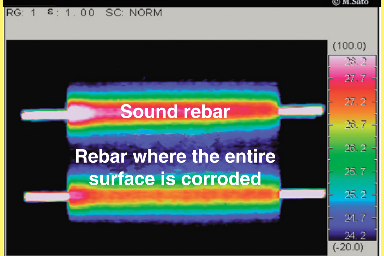


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# Foreword

This is the latest issue of “Science and Technology Trends — Quarterly Review”.

National Institute of Science and Technology Policy (NISTEP) established Science and Technology Foresight Center (STFC) in January 2001 to deepen analysis with inputting state-of-the-art science and technology trends. The mission of the center is to support national science and technology policy by providing policy makers with timely and comprehensive knowledge of important science and technology in Japan and in the world.

STFC has conducted regular surveys with support of around 2000 experts in the industrial, academic and public sectors who provide us with their information and opinions through STFC’s expert network system. STFC has been publishing “Science and Technology Trends” (Japanese version) every month since April 2001. The first part of this monthly report introduces the latest topics in life science, ICT, environment, nanotechnology, materials science etc. that are collected through the expert network. The second part carries insight analysis by STFC researchers, which covers not only technological trends in specific areas but also other issues including government R&D budget and foreign countries’ S&T policy. STFC also conducts foresight surveys periodically.

This quarterly review is the English version of insight analysis derived from recent three issues of “Science and Technology Trends” written in Japanese, and will be published every three month in principle. You can also see them on the NISTEP website.

We hope this could be useful to you and appreciate your comments and advices.

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# Executive Summary

**Information and Communication Technologies**

## 1 Ontology for Cross-Organizational Communication

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Japanese people are usually shy of, and do not try hard to push communicating across organizational boundaries. However, such communication is said to be crucial to creating innovations, and is also essential to industry-academia collaboration and other endeavors to develop interdisciplinary science and technology fields that converge heterogeneous sciences and technologies.

Innovation is also needed in non-scientific areas, such as new business models and approaches to customers, the development of which usually requires collaboration among different organizations and thus cross-organizational communication. This report focuses on ontology as an information technology for cross-organizational communication, even though ontology is fundamental mechanism to structuring, describing and displaying information as the content of communication.

Although ontology has its origin in Greek philosophy, today's ontology as an information technology emerged around 2000, driven by computer-aided document processing, knowledge engineering, which seeks practical applications of artificial intelligence research results, and the Semantic Web, which aims to achieve a next-generation Web. Only recently has ontology become clearly recognized as a fundamental tool for communication.

As notation standards for ontology are being developed, initiatives have launched in many parts of the world for the development of related tools and the collection of ontology data based on these standards. One of the science and technology fields eager to benefit from ontologies is genetic research and development (so-called Gene Ontology). However, even in this domain, data and frameworks for ontology description have yet to be standardized.

In terms of the capacity to support cross-organizational communication, ontology is superior to conventional technologies in several respects, especially when it comes to creating electronic documents. These advantages include machine processability, interoperability, and a structure designed to allow translation into other languages or cultures. However, efforts to use ontologies for cross-organizational communication have just begun, which means that technical development is still in progress.

Many challenges still remain to be overcome. They include, for example, social aspects of the communities for which ontologies are created, intellectual property rights over knowledge structures that are described using ontologies, technologies to guarantee the safety and safe sharing of knowledge and the potential for a completely new form of communication. Some organizations are making attempts to ensure that their existing business knowledge is maintained and passed on to the next generation by explicitly representing such knowledge through the use of ontology technology. In a sense, these attempts are aimed at achieving communication across not just organizations, but also various times.

(Original Japanese version: published in April 2007)

Environmental Sciences

## 2 Considering of Lightning Damage Protection and Risk Reduction for a Safe and Secure Society

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Because lightning does not occur that often in Japan, it is not something one experiences every day. When it does occur, however, lightning strikes can cause major damage such as blackouts, as well as injuries to people.

Our advanced information society is increasingly vulnerable to lightning. Momentary voltage drops and lightning surges through networks caused by lightning strikes do not only damage network devices, cause shutdowns, and damage electric home appliances. For example, momentary voltage drops at semiconductor manufacturing works and so on that interrupt manufacturing, causing problems such as decreased yield, are increasing. Noise generated by lightning strikes is lower in voltage and higher in frequency than surges are, so it does not destroy light electrical components containing semiconductors. However, it can generate enough abnormal voltage to cause fire alarms to malfunction or to cause the data on computer disks to be lost. Furthermore, in recent years, there have been reports of people being burned by electromagnetic wave induction generated by lightning.

With the adoption of wind power generation equipment, Japan has also seen new forms of lightning damage. In the case of winter lightning on the Sea of Japan side, one wind power turbine was struck by lightning more than 100 times in a single year. Other windmills reportedly have had lightning damage repair costs over five years that equaled their original construction costs. Furthermore, the construction of tall structures such as windmills and towers changes surrounding environments and can increase the number of lightning strikes. Creation of detailed diagrams of the relationship between lightning-prone areas and structures, reexamination of the economics of wind power generation, and research on technologies for lightning countermeasures are desirable.

Furthermore, discharges occurring above thunderclouds have also been observed to generate $NO_X$ that can cause acid rain, electromagnetic waves, x-rays, and gamma rays. They have been implicated in environmental problems and communications failures. Regarding lightning, although the mechanisms of its generation are understood, much remains unclear about discharge behavior within clouds. Currently, research to observe and predict lightning from space is planned. With the present observation system and technology, lightning occurrence, which is a local weather phenomenon, is impossible to predict accurately. Accurate data on the number of lightning strikes that occur is not available to the public. More accurate forecasting and more advanced information transfer are necessary for the prevention of lightning damage. It is necessary to collect the data that are currently scattered and create an environment that makes it easy for users to select countermeasures. To prevent damage in general, the construction of networks for prompt transmission of lightning information is an issue. Lightning current penetrates buildings by various routes, and different government agencies have jurisdiction over the different routes. Because of this problem, the creation of measures that span agency boundaries is necessary. Examination of upgraded standards suited to the information society is also vital. In particular, confirmation of differences with the standards of Europe and the USA in fields where the usage of foreign equipment is increasing and consideration from the design stage of buildings are necessary.

Furthermore, a problem shared among developed nations including Japan is declining student interest in electrical engineering, including high-voltage engineering. Already, the elimination of university courses on high-voltage is causing problems with the training of successors in the field. It is necessary to build frameworks to enable the Japanese people to appreciate the importance of energy.

(Original Japanese version: published in April 2007)

**Nanotechnology and Materials**

## 3 Analysis of Japan's Nanotechnology Competitiveness
### — Concern for Declining Competitiveness and Challenges for Nano-systematization —

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The beginning of the promotion strategy for the nanotechnology and materials field in the "Third Science and Technology Basic Plan" states, "Japan's materials technology... is firmly established at the world's highest level for all stages, making them the source of the global competitiveness of Japan's domestic manufacturing." This statement, however, applies to materials technology alone. Although the strategy states that nanotechnology ("nanotech") is also at the world's highest level, it says, "the source of Japan's strength in nanotechnology is its strength in materials technology." Indeed, an increasing number of Japanese nanotech experts are experiencing a sense of crisis or a feeling of being stymied regarding Japanese nanotech. Based on research papers, patents, and survey results, this article intends to discuss, by examining nanotech's technological characteristics and industry structures, Japan's nanotech competitiveness and changes in the competition areas of nanotech, which are difficult to grasp through quantitative analysis alone.

A finding from this study is that in individual technology areas identified through an analysis of papers and patents, Japanese nanotech can be rated equal to or just behind that of the US. In the future, however, when nanotech commercialization becomes more widespread and the stages of technology competition change, Japan may lose relative competitiveness as it faces the following two types of barriers related to "systematization."

1) **The challenge of developing functional nanosystem materials designed at the molecular level**

   The stages of competition in nanotech are undergoing a transition. That is, they are shifting from top-down technologies, which aim to improve materials functions and characteristics through repeated scaling down for overcoming traditional technical challenges, to bottom-up technologies, which seek to fabricate nanosystems from nano-functional materials that are to be ultimately designed at the molecular level. The concern is that Japan, which has developed its strength in top-down technologies, might gradually lose competitiveness as the competition shifts to bottom-up technology stages. In order to successfully develop bottom-up technologies and ultimately achieve technologies to fabricate nanosystems, science-based research and development to support them are essential. Nanotech researchers should facilitate basic research with emphasis on such highly uncertain R&D, first by building and promoting basic research methods for nano-systematization, which are yet to be established.

**2) Construction of an innovation system aiming for nanotech commercialization**

Nanotech, particularly its bottom-up technology, involves high uncertainty due to its technical characteristics. Its R&D thus requires long-term, continuous, and incremental investment. In Japan, an innovation system enabling such investment has not been sufficiently established as a supplemental system. From the perspective of policy and investment, a key requirement is designing an innovation system that incorporates a mechanism for risk distribution.

Technology roadmaps have played a role in securing the rationality of advance investment by clarifying the direction of investment and even predicting socioeconomic ripple effects. With future nanotech focused on bottom-up technologies aimed at nano-systematization, however, current methods of drafting and implementing effective strategies are reaching their limits because of extremely high technical uncertainty. This suggests a need for new methods for creating strategy management tools that accommodate these characteristics of nanotech.

(Original Japanese version: published in May 2007)

Energy

## 4 Research and Development Trends in Energy Crops and Biofuel Conversion Technologies

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To solve global warming problems and achieve sustainable development of the economy, it is necessary to increase the use of renewable biomass resources. In many countries, there are strong movements to accelerate the spread of biofuels as an alternative to petroleum.

In overseas countries, especially the U.S.A., the EU and Brazil, there are active movements to exploit their vast lands to cultivate crops used for producing energy (energy crops) and to use biomass-based fuels such as ethanol and rapeseed oil as automobile fuels. These biofuels may be sufficiently competitive in price with conventional fossil fuels if crude oil prices exceed US$50/barrel. From medium- and long-term perspectives, given that production of crude oil are expected to reach their peaks and crude oil price will be steady at a high, the U.S.A and European countries consider biofuels to be the most promising candidates for alternative fuels in the transport sector. They are taking measures to support the introduction of biofuels, and actively making research and development efforts to ensure the stable supply of biofuel resources in the future.

In Japan, the “Kyoto Protocol Target Achievement Plan”, which was decided by the Cabinet Council in April 2005, set a target of 500 thousand kl-crude oil equivalent for biofuels used in the transport sector. The “Biomass Japan Comprehensive Strategy Promotion Council” in 2006 estimated that the potential production of ethanol from domestic biomass resources might reach 6 million kl/year, equivalent to about 10% of the annual consumption of gasoline in Japan. However, no biofuel that is competitive in cost with conventional fossil fuels has been introduced into Japan, where at best only 40% of the food supply is produced domestically. For the time being, therefore, it is unlikely that the government will impose obligatory medium- and long-term targets for the introduction of biofuels, establish biofuel introduction programs, or provide incentives such as changes to the taxation system.

In view of the land potentially available worldwide, it is estimated that the demand of foods will still be compatible with that of biofuels around 2050 when the total world population is expected to peak in this article. The full-scale introduction of biofuels will require Japan to make efforts not only in obtaining and diversifying domestic natural resources, but also in acquiring and maintaining Japanese interests in overseas arable lands used for producing energy crops. The land areas used for producing biofuels are expected to increase in the future. To acquire overseas biomass resources, it is important for Japan, a country largely devoid of biomass resources, to develop its own unique biofuel conversion technologies (such as bio-ethanol and bio-diesel conversion technologies using energy crops and lignocellulose as raw materials) which cannot be provided by other countries, especially those countries rich in biomass resources. However, an international comparison of the number of science and technology papers published on biofuel-related technologies revealed that the number of papers published by Japanese researchers was smaller than those by American and European researchers in every biofuel-related field of research. In addition, the accumulated results of research in Japan have not been effectively utilized, especially in the discipline of microbiology, mainly fermentology, where Japanese researchers are considered to be strong.

To promote future technological developments in Japan, it is necessary for the Japanese Government to set definite national targets and timeframes for the introduction of biofuels and to review realistic strategies and social systems for acquiring natural resources. It is also necessary to prepare a plan for directing R&D efforts to develop second-generation biofuels that matches the chosen strategy and system. To do so, it is important to clarify the agronomic conditions of lands, such as weather and soil, with the potential to produce energy crops and to focus research on a narrow range of targets. Research on second-generation biofuels covers both energy and life-sciences fields. Therefore, it is important to actively promote the merging of research programs by human exchange between the two fields and the establishment of cooperative research centers.

(Original Japanese version: published in June 2007)

**Social Infrastructure**

## 5 Technology Trends in Stock Management of Road Structures

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Because of the intensive construction of the road structures that support Japan's economy and national life during the period of high economic growth from 1955 through 1970, these road structures will deteriorate en masse, peaking around 2020 through 2030. There is concern that the investment required for maintenance, operation, and renovation may increase dramatically, imposing a heavy burden on the nation's finances. Bridges constructed during the period of high economic growth account for around 34 percent of all Japan's bridges, while tunnels built during that period account for approximately 25 percent of all tunnels. It is estimated that about 20 years from now, the number of bridges on general national highways and regional roads that are at least 50 years old will number eight times as many as in 2005, while the number of tunnels that old will triple. Furthermore, with problems such as the people's needs regarding infrastructure diversifying and environmental measures coming to the fore, as well as population decline, a low birth rate, a larger number of elderly people, and difficult financial conditions, renovation of aged infrastructure will certainly become more difficult. Therefore, in order to efficiently operate and maintain infrastructure, steadily shrink life-cycle costs, extend the life spans of the infrastructure essential to national life, and avoid risks such as bridge collapses, infrastructure improvement through stock management responsive to social change will become vitally important.

The "corrective maintenance" utilized to date must be shifted to "preventative maintenance." In order to standardize replacement periods, shrink life-cycle costs, and reduce risk, a systematic response to the following points is necessary.

**(1) Full-fledged adoption of stock management methods**

Maintenance methods should be shifted from "corrective maintenance" to "preventative maintenance." Rather than relying on the piecemeal performance of inspection, evaluation, deterioration prediction, and so on of structures that has been carried out to date, stock management systems integrating these elements should be constructed. Early, full-fledged adoption and operation of preventative maintenance is necessary to ensure the long life and use of existing stock.

**(2) Technical development**

Instead of individual institutions pursuing research in isolation, industry, government, and academia should collaborate on R&D projects to elucidate the causes of deterioration, further improve deterioration prediction technology, non-destructive inspection technology, and monitoring technology, and develop effective and economical repair and reinforcement methods. They also need to work together to increase structure longevity, and improve inspection and renovation technologies that minimize impacts on transportation and the environment when replacements are made. They should establish a roadmap to promote research and development.

**(3) Development of human resources with advanced measurement and judgment skills**

In order to properly maintain and manage aging structures as their number increases, more technicians who can apply a high level of knowledge, experience, and appropriate technical judgment using stock management methods at all stages, from design through construction, inspection, and operation and maintenance, will be necessary. In-house technicians and consulting technicians should be upgraded through on-the-job training and other hands-on training. Establishment of a certification system in accordance with levels of technical ability is needed.

**(4) Technical and financial support for local governments**

Local government agencies operate and maintain a high percentage of road structures. In many cases, financial constraints and a shortage of technicians in local public agencies mean that operation and maintenance are insufficient. Improving the management of regional roads is a key point in raising the overall level. Promotion of the implementation of the PFI, which involves the national government in the utilization of private-sector funds, and creation of measures for the support of local governments in financial difficulty will also become necessary. In addition, the national government, universities, and independent administrative agencies, foundations, and incorporated associations involved with social infrastructure will need to take the initiative in providing technical support to local governments.

(Original Japanese version: published in May 2007)

Science & Technology Policy

## 6 Report on the AAAS Forum on Science and Technology Policy

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A two-day Forum on Science and Technology Policy was held by the American Association for the Advancement of Science (AAAS) on May 3 and 4, 2007, in Washington, DC. This policy forum has been held every spring since 1976. This year's was the 32nd. (The name was changed from "colloquium" to "forum" beginning in 2004.) Over 400 people participated, including government officials such as John H. Marburger, III, Science Advisor to the President (and Director, White House Office of Science and Technology Policy), who attended for the sixth straight year; members of the legislative branch; university educators and researchers; researchers and analysts from relevant think tanks; members of relevant academic societies; and people involved with science and technology policy in other countries.

Presidential Science Advisor John H. Marburger offered the keynote address. He gave his thoughts on changes in the Federal research and development budget. He discussed the case of the NIH's R&D budget doubling over the five years ending in FY 2003, bringing about an increase in the number of researchers. He pointed out that it will be difficult to maintain this rapidly expanded number of researchers using the conventional business model. He indicated that he thinks that university research is beginning to diversify funding sources by turning to new business models such as building new relationships with private-sector sponsors, and that the Federal Government is encouraging such changes.

The themes for the plenary sessions were the AAAS analysis of the federal budget proposals for R&D in FY 2008, issues in pharmaceutical and biotechnology R&D, and issues regarding sequestered science (concealing and revealing scientific information). AAAS R&D Budget and Policy Program Director Kei Koizumi reported that because of the Bush Administration's goal of erasing the deficit and balancing the budget by 2012, the Federal R&D research budget for FY 2008, with the exception of some items related to the American Competitiveness Initiative (ACI), will be cut, as it was in FY 2007.

In the discussion of the issue of productivity in biotechnology, it was noted that despite enormous investment, the number of FDA approvals of drugs and biomedical agents is not increasing. It was pointed out that because regulatory frameworks are not keeping pace with the rapid development of medicine, reform of the regulatory process is necessary. In addition, the question of whether scientific information should be sequestered was discussed. While sequestering information for reasons such as protecting research progress or intellectual property, protecting privacy, or guarding from terrorist risks is not improper, disclosure is essential when risks to public health are involved. The opinion that effective and functional guidelines for handling scientific information are necessary was offered.

Themes in the concurrent sessions included states' expanding roles in science and technology; building science, technology, and innovation capacity in developing nations; and surveillance, privacy, and the roles of science and technology. Although national security issues were a major topic in previous forums, this year's subjects for discussion were narrowed down to surveillance technologies and privacy and social issues.

(Original Japanese version: published in June 2007)

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# Ontology for Cross-Organizational Communication

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## 1 Introduction

Industry-academia collaboration and other forms of communication across organizations are a prerequisite for developing science and technology and creating innovations. For example, converging technology, which Western countries are beginning to promote for innovation creation, is an approach whereby heterogeneous sciences and technologies are converged[3] and cross-organizational communication is essential to the development of such a technology. As the Innovation 25 Strategy Council pointed out, creation of innovations requires not only scientific and technical development, but new business models and new social mechanisms as well. New business models also call for innovative approaches to customers, involving collaboration across different organizations and domains and therefore needs cross-organizational communication.

However, Japanese organizations are said to have a high wall separating science specialists and non-science specialists. Even within the same scientific field, people tend to be shy of interacting across organizational boundaries. A first step to achieve cross-organizational communication is to encourage people to engage in outside communication and to create opportunities for such engagements. This would require a mechanism for supporting such communication and, more importantly, organizational efforts to fully exploit rapidly advancing information technology.

Basic and common examples of information and communications technologies to enable such communication are e-mail and the Web (browser), which are accessible via mobile telephones and PCs. Recently, social networking services (SNSs) and blogs are attracting attention as new communication tools. They are helping to improve communication devices and their associated operations, making the information being communicated more easily accessible.

This article focuses on ontology as an information technology, that is fundamental to structuring, describing and displaying information as the content of communication. Few people have come up with concepts on how to use information technology to structure or describe the information being communicated, except for basic hardware-oriented approaches such as using a computer's word processor instead of pen and paper. Only recently has ontology become clearly recognized as a fundamental tool for communication[4].

Ontology contributes to not just person-to-person communication, but more remarkably to organization-to-organization communication as well. In other words, although it is individuals that are engaged in communication, in many cases, the target of communication for each of them exists only beyond the boundary of their respective organizations. To enable such communication, each participant must be aware that the "common sense" of his or her organization may not applicable to other organizations. Unlike person-to-person private communication, in which both parties can express their thoughts in their own language, cross-organizational communication requires each party to describe the information needed by the other party in a mutually understandable language. For this kind of communication to be achieved, an organizational approach to information structure and usage is needed, therefore information technologies such as ontology can be useful and effective.

With attention to cross-organizational communication assisted by ontology, this report explains what ontology is, describing its historical background and current situation. There are initiatives for ontology standardization as well as efforts to develop related tools, contributing to the collection of ontology data. Nevertheless, ontology is a technology still in the course of development, and many challenges are expected to surface in areas such as the handling of intellectual property rights and the management of information security, as further progress is made.

## 2 Historical background of ontology

### *2-1 Ontology as a technology and ontology in philosophy*

The term "ontology" does not date back very far. According to the Oxford English Dictionary, the term first appeared in 1721 and was explained as "an Account of being in the Abstract," which refers to the philosophical aspect of ontology. Therefore, the Japanese translation of "ontology" in the philosophical context is "sonzairon," which literally means the study of the nature of being. Studies on ontology in Western countries date back to scholastic theology and even to Greek philosophy. The main question of Aristotle's metaphysics was, "What is the meaning of being?" This question is still being studied today in Husserl and Heidegger's contemporary philosophy, and can be traced back in the theology of Thomas Aquinas in 13th century, Leibniz in 17th century, and Kant in 18th century who founded modern philosophy.

However, "ontology" as used in the context of this article is in a completely different domain than ontology in the philosophical context, although the same term is used. Ontology in the technical context uses the same questions such as "What kinds of entities constitute the world?" and "What kinds of entities exist in the world?" that have been echoed in the history of ontology in philosophy. The perspective of these questions fall into the computer world (or the Web world), not the human world. By the way, I should mention here that some people started to reinvestigate and try to connect ontology technology with philosophical ontology recently. Some researchers even advocate that debates from philosophical perspectives should be resumed in order to overcome the limitations of current ontology[6]. They suggest that cross-organizational communication should be based upon such questions as "What is an organization?" "What is the goal of the organization?" and "What does the organization exist for?"

### *2-2 History of ontology technology*

As mentioned in the previous section, the origin of current ontology technology is not directly related to communication, although philosophical ontology that deeply underpins the technology is, of course, connected to communication. Historically, ontology research and development to date has diverged in two different directions.

One of the roots is an offshoot of knowledge engineering, which seeks practical applications of artificial intelligence research. Ontology research in this direction is aimed at "an explicit specification of a conceptualization" with regard to knowledge, as a commonly used definition by Gruber[5]. In ontology engineering, an ontology is defined as "a structure of concepts or vocabulary for artificial intelligence systems and theory for such structuring"[6]. Such ontologies have been used in knowledge engineering applications, such as expert systems, for resolving difficulties associated with corrections and updates of knowledge. In short, such R&D has been conducted to specify the conceptual structure underlying the knowledge base being used and to facilitate the maintenance of the knowledge base.

Another direction of ontology research came from the advances in Web usage. This can be divided into two approaches. The first is Topic Map technology[7] (explained later in Chapter 3), which originates in index processing for document handling dating from 1991. This technology is based on HyTime (Hypermedia/Time-based Structuring Language), an SGML (Standard Generalized Markup Language)-derived markup language applied to multimedia/

hypermedia. Topic Map has been standardized as ISO/IEC 13250:2000/2003 which is a standard for advanced information exchange which expresses knowledge about the subject of the information being sent. Following the advent of XML (eXtensible Markup Language), a successor to SGML, syntax has been extended to be applicable to XML and the Web. Topic Map data model has also been defined. Current standardization activities include canonicalization, the reference model, compact syntax and graphical notation. Topic Map related standards are also being developed, including ISO 18048 TMQL (Topic Maps Query Language), ISO 19756 TMCL (Topic Maps Constraint Language), and ISO 29111 (Expressing Dublin Core Metadata using Topic Maps). In Topic Maps, subject type, subject relationship (association) type, and subject-resource relationship (occurrence) type are regarded as ontologies.

Another approach in advanced Web usage is the Semantic Web[8]. This involves tagging, which is a set of techniques to add knowledge to enable advanced processing in the Web. R&D on the Semantic Web started in 1998 with a view to achieving a next-generation Web. Ontologies in this field are also called Web ontologies. This third direction, the Semantic Web, surpasses the previous two in terms of the R&D population and the level of attention. However, ontologies were not emphasized in this field initially.

Tim Berners-Lee, the inventor of the World Wide Web (WWW), published some memos on the Semantic Web in 1998[9-11]. This has led to ontology development in this field. One of these memos is the text of his keynote speech titled "Evolvability," which was delivered at the Seventh International World Wide Web Conference. In this speech he referred to ontology like this: "Strengthening the logical aspect of schema language requires not only relational databases, but also the cooperation of knowledge processing experts"[11]. Berners-Lee himself considers artificial intelligence as part of "what the Semantic Web isn't," suggesting his intention to separate the Semantic Web from failed technology tried in artificial intelligence research[10]. He was looking to things that can "globally" handle knowledge and tried to eliminate "centralist assumptions," which caused the failure of traditional knowledge base projects. During his keynote speech at XML 2000 in Washington, D.C. in 2000, he also mentioned RDF (explained later in Chapter 3) and Topic Maps as enablers of the Semantic Web and stressed the need for integrating them[12]. On the other hand, in his paper published in Scientific American in 2001, Berners-Lee defined an ontology as consisting of descriptions of the relationships between concept sets and the inference rules governing them, citing ontologies as the third key enabler of the Semantic Web[13]. Since then, ontologies have become a prerequisite for the Semantic Web.

The history of ontology technology described so far, whether in connection with the Semantic Web or knowledge engineering, tells you that it heavily depends on computer processing. Topic maps, too, were originally developed for document processing, and proceeded for computer-aided knowledge data structuring, such as information management and information searching. However, some new ideas recently propose the direct use of ontological knowledge expressions and structures for human communication rather than computer processing[4, 14]. Although still technically under development, such communication based on novel ideas may in the future replace current human communication that are bounded in literal words.

## 3 Ontology technology development status

This chapter describes the current status of ontology technology development from three perspectives: standardization, tool development and data accumulation.

### *3-1 Standardization of ontology description*

Historically, the standardization of ontology description originates in the development of topic maps in the early 1990s. However, this section begins with the Resource Description Framework (RDF), which has a simpler standard format and will therefore make it easier to understand the other standards. Descriptions in RDF use

XML (eXtensible Markup Language) format. XML is a standard format similar to SGML and HTML, and was developed by the World Wide Web Consortium (W3C), a Web technology standardization body. Its first version has become a Japanese Industrial Standard (JIS X 4159:2005) and has been released in Japan.

**(1) Resource Description Framework (RDF)**

The Resource Description Framework is literally a framework for describing resources on the Web. RDF is primarily considered a model and a description language. W3C recommendations consist of six elements (RDF Primer, RDF/XML Syntax Specification, RDF Vocabulary Description Language: RDF Schema, RDF: Concepts and Abstract Syntax, RDF Semantics, RDF Test Cases), and their specifications are available at http://www.w3.org/RDF/.

Although RDF is essentially a framework for handling resources on the Web, it can actually deal with concrete objects residing outside the Web and abstract concepts. It uses Uniform Resource Identifiers (URIs) to refer the resources. The description format for the URI is separately defined as the URI Scheme. In general, URIs use Uniform Resource Locators (URLs) to identify the location of Web resources, and character strings to identify the other objects. A resource is expressed by a triplet: the subject representing that resource, the property (or predicate) and the property value (or object). URI notation usually uses either XML or directed graphs. Elements of these notations rely on character strings called RDF URI references. For objects not existing in the Web, a special notation known as blank nodes is used.

The original purpose of the creation of RDF was to enable machines to process Web resources. XML notation is also designed for machine processing, while graph notation is aimed at helping human understanding. One should note that although RDF describes properties of individual resources, it cannot represent such issues as sets of resources, general relationships between resources, and relationships between properties. These should be specified in the RDF Schema in the RDF vocabulary description language. The RDF Schema adopts concepts such as object-oriented class, domain and range, which can represent concepts similar to functions in mathematics.

**(2) Web Ontology Language (OWL)**

OWL is an abbreviation of Web Ontology Language. This is an extension of RDF, and thus an RDF document may be interpreted as an OWL document. OWL has inherited syntax from RDF. OWL functions consist of class descriptions, set operations for classes, and class axioms, which describe relationships between classes. Although there are some additional functions concerning properties and class members, their number is limited because additions to the RDF Schema by OWL are confined to descriptions of relationships between concept sets. Class description is also possible in the RDF Schema, but OWL additionally incorporates relationship descriptions including set operations as a standard.

A notable fact about OWL is that it is part of a large project, namely, the Semantic Web. OWL is becoming recognized as a standard ontology description language even in non-Web related areas, driving moves to create resources for OWL, such as libraries, special search sites, and software tools like description editors and inference engines.

**(3) Topic Maps**

The development of Topic Maps as a standard began in 1991, ahead of the development of RDF and OWL, as mentioned in Chapter 2. Although originally designed to enable index processing associated with machine-based document processing, topic maps can now handle information on the Web just as RDF and OWL do. Topic Maps are significantly different from RDF and OWL in that they discriminate between the information layer in which information content exists and the knowledge layer for relationship description. A Topic Map description consists of three major elements: topic, association, and occurrence. A topic is a computer-based expression of the subject and has a base name and multiple variant names. The subject of a topic is identified using either the subject locator or a combination of the subject indicator and the subject identifier. An association, which is roughly equivalent to the property in RDF, is not directional and is specified for multiple topics. Furthermore, topics participating in an association are assigned association roles. An occurrence is a link to information in the information layer and includes a URI to indicate the location of information. There are multiple types of topics, associations and occurrences, each of which is assigned a specific scope. The notion of Published Subject Indicators (PSIs) has been adopted to allow the consistent use of common subjects. The W3C has made a proposal to achieve standardized interoperability between RDF and topic maps[15].

### *3-2 Software tools*

Notation standardization in ontology technology has promoted the development of software tools to deal with standardized documents. Major software tools has been already developed such as editors for standardized description, tools to integrate and consolidate multiple ontologies after their creation, and inference engines for inference based on relationship descriptions included in ontology data.

Currently, the most advanced area in development and proliferation is for editors, i.e. entry tools for ontology. Protégé (http://protege.stanford.edu/), developed by Stanford University, has almost become a de facto standard, with 62,000 registered users (as of April 2007) and international conferences being held every year. Protégé provides two kinds of editors: Protégé-Frames and Protégé-OWL. Protégé editor users can obtain applications and extensions known as plug-ins, as well as ontology data created using Protégé. Plug-ins for diverse areas are available, including biomedical informatics, project management, search and navigation, visualization, import & export, inference & reasoning, Semantic Web, terminologies, software engineering, code examples, and natural language processing. Ontology data sets, which are available as libraries, are accompanied by frame-based data examples, OWL data examples and examples of data in other formats. Protégé is open-source software, which means a community of registered users is responsible for its development and maintenance.

For inference engines, which the Semantic Web emphasizes, no standard tools like Protégé have been developed. However, several types of engines already exist, with some of them commercially available.

A typical topic map tool is the one released by Ontopia, the Ontopia Knowledge Suite (OKS). Other examples include Topic Maps 4 Java (TM4J), an open-source project[7].

### *3-3 Collecting ontology data*

More and more people are involved in the creation of ontology data and making them available to others, often through Semantic Web projects. Even an ontology search engine for the Semantic Web, called Swoogle[16], has appeared. According to its data, as of April 2007, there are about 2 million Semantic Web documents and about 374 million elements. Swoogle extracts Semantic Web documents, which are identifiable by the .rdf or .owl extension, from documents found with the Google search engine, and then reads these documents' ontology structure written in XML to interpret the content. While the current Google engine does not handle such semantic data descriptions, Swoogle's search robot is designed to use the ontology data obtained like this to automatically search through other ontological documents[17] *1. Stanford University's Protégé Web site mentioned above also offers ontology data sets written in OWL and many other formats.

Such moves have led to standardization under ISO/IEC 19763-3 for ontology metadata registration[18].

Constructing ontology data, even if their scope is limited, actually involves the cumbersome work of listing all the concepts within that scope and describing relationships between them. Apart from this traditional centralized approach to ontology data construction, a new approach has been proposed which uses a collaborative method that develops ontologies by allowing participants to add tags to freely describe the content. This approach (known as folksonomy) suggests that semi-automatic collection of ontology data may be possible, although their tags may not be exact conceptual elements nor relationship descriptions for ontology[21].

### 3-4 Science and technology fields actively using ontologies

One of the science and technology fields eager to benefit from ontologies is genetic research and development (so-called Gene Ontology). However, even in this domain, data and frameworks for ontology description have yet to be standardized. For example, a Web site called "Standards and Ontologies for Functional Genomics"[19] declares, "Numerous ontologies for human and mouse anatomy exist or are being developed. Each has its own purpose. For the biologist who wants to annotate data with anatomical names this variety is confusing". To mitigate such confusion, this site intends to provide a place for interaction.

Another Web site, Open Biomedical Ontologies[20], introduces nine related projects and lists ontology data files in 63 domains, in an attempt to provide links to diverse initiatives by different groups.

Developing an ontology of the knowledge owned by an organization requires substantial efforts and money. This is demonstrated by the College of American Pathologists (CAP) of the U.S., which has created SNOMED-CT, a large ontology consisting of as many as 340,000 concepts and 870,000 terms related to them. The ontology is offered at a licensing fee of US$32.4 million[24].

## 4 Ontology for cross-organizational communication

### 4-1 Different aspects of ontology

The idea of using ontologies for the sake of communication is relatively new, as explained in the section on the historical background of ontology, and only recently did researchers begin addressing ontology from this perspective. An example of ongoing projects to develop ontology-based communication tools is Semantic Authoring by Hasida and others at the National Institute of Advanced Industrial Science and Technology, a project that uses a semantic editor[4, 14].

Roles of ontology for cross-organizational communication are twofold. First, it is a tool to organize or systematize knowledge or to give everyone an at-a-glance picture of the knowledge structure of an organization ("visualization")[2]. Second, it is a technology aimed at removing subtle obstacles from linguistic expressions so that cross-organizational communication can be smoothed through the direct use of ontology descriptions which conveys the basis of the information being communicated[4].

From a different viewpoint, ontology can also be divided as descriptions of the semantic structure of specific information (more exactly, what can be called semantic expressions of information using an ontology, or simply ontology data), and as computer systems to enable such ontology-based expressions and collections of computer processes applicable to such expressions (more exactly, what can be called ontology tools and environments).

### 4-2 Explicit representation of an organization's knowledge

There have been a number of attempts to achieve the task of clarifying an organization's knowledge, especially informal, tacit knowledge[23]. Ontologies can be considered as a technique to explicitly specify such knowledge.

In this context, the knowledge for which an ontology is created is not simple numeric information, but in principle the terminology used in the organization, concepts represented using this terminology, and relationships, especially set relationships between these concepts. For example, the knowledge addressed here does not refer only to numeric information such as output, work in process, and inventory in a production division, or cash flows, sales by item, and profits in an administrative division. An ontology expresses the knowledge representing concepts behind such numeric information and relations between them. A new trend in recent years is using multimedia, such as still images, audio and movie pictures, instead of words, for representing knowledge concepts.

In terms of explicit representation of knowledge, ontology is superior to other information-related technologies (for example, a technology to create electronic documents including multimedia objects and hyperlinks) in the following respects.

(1) Ontology explicitly expresses relationships between concepts in graph structure, thus enabling machine processing with no human assistance.
(2) For ontology, established standard description formats exist, such as OWL and topic maps. Therefore, it allows the mutual exchange, comparison and merging of ontology data relatively easily, providing superior interoperability.
(3) For their standard description formats and graph structure, ontology data can be translated into other natural languages or environments with different cultures relatively easily.

## *4-3 Challenges*

Ontology for cross-organizational communication still has many challenges to overcome.

**(1) Social aspects of the community**

Since an ontology incorporates an organization's knowledge, it should primarily be shared among the organization's members. However, taking the possibility of communication across organizations into account, an ontology should address a broader community consisting of everyone associated with that knowledge. Ontologies so far have mostly been indifferent to sociological aspects of such a community because their scope was confined within information technology. However, it is now necessary to address more explicitly the community that consists of all the people related to the organization's knowledge, and the social aspects of such a community, because a number of challenges stem from such a community—including the issues of validating a knowledge structure created using ontology technology, verifying an inference in a graphic relationship description, and changing (evolving) concepts and their relationships.

**(2) Intellectual property rights**

A knowledge structure expressed using ontology technology can be subject to intellectual property rights. However, fundamental and common knowledge used by an organization or an industry should essentially be disclosed for wider public use. For example, traditional knowledge structures like dictionaries have been protected as publications under intellectual property rights. Since ontologies are supposed to be used for day-to-day operations, their treatment as intellectual property is far more complex than it is for publications. An ontology that explicitly describes an organization's expertise is a source of the organization's value, and therefore should be considered invaluable and in need of strict protection.

**(3) Safe sharing**

As in the case with any other artificial object, ontologies are not free from errors and defects. In particular, the possibility of machine processing based on ontology data implies that erroneous processing using erroneous ontologies may lead to fatal results. How to ensure the safe use of ontologies is a challenge to be overcome in the future. The sharing of an ontology among different organizations poses particularly diverse risks.

**(4) Emergence of new forms of communication**

It is true that a general debate should be held on which direction ontology-based communication should develop in order to achieve more efficient communication, but there is a possibility that ontology evolves to a completely new form of communication that complements traditional natural language communication. Even today, some people speculate that youth, now deeply reliant on messaging via mobile phones, are lacking in the ability to communicate in traditional language. This leaves a question to be answered in the future: Can ontology-based communication enable more efficient and less misleading communication by making it possible to omit the interpretative process in traditional natural language communication, or will it weaken natural language communication?

### 4-4 Status of cross-organizational communication in Japan

As explained in Chapter 1, in Japanese organizations, there is a high wall between science specialists and non-science specialists, and people tend to shy away from interacting across organizational boundaries even when they focus on the same scientific field. This is said to have a harmful effect in many ways.

As an example, take iPod, a portable music player. There is a view that in spite of Japanese companies' competitiveness in the development of components and the availability of all the necessary components, including music distribution systems, in Japan, it was not a Japanese company but Apple that was able to integrate these components across conventional industry sectors and organizations to create iPod[1]. Another example is the weakening of the competitiveness of the once-dominant Japanese semiconductor process industry, which is partly attributed to a delay in integrated accumulation of knowledge on and expertise in semiconductor production systems. One researcher argues that the Japanese semiconductor process industry has lost its competitiveness because at the time when it was vital for semiconductor manufacturers to share knowledge among many stakeholders in production-related divisions, (so that knowledge conversion could be achieved quickly and autonomously where needed), the industry failed to share knowledge and keep the traditional operation that the knowledge is acquired and used by limited individuals[2].

Another study attributes the lack of cross-organizational communication in Japanese organizations to, in addition to technical shortcomings, the absence of the willingness to initiate such communication and a trait characteristic of Japanese organizational culture that tends to deny such communication. In other words, Japanese organizations lack certain necessary mindsets for cross-organizational communication[25].

Although ontology as a communication technology is not able to directly influence this lack of certain mindsets, the act of expressing an organization's knowledge using ontology may motivate its members to actively compare their organization with others', for example, through a comparison of their ontology with another organization's ontology. For example, in a project to develop a software system, the system developer needs to fully understand the needs of system users. This would require cross-sectional communication, but in reality, such projects often fail to deliver the best possible system due to misunderstanding[26]. There are attempts to solve this problem by describing the knowledge of system users by using ontology so that the developer can fully understand it and effectively perform high-level processes in system development.

In Japan today, where experienced and highly intellectually skilled workers are retiring in large numbers, some organizations are making attempts to ensure that their existing business knowledge is maintained and passed on to the next generation of workers by explicitly representing such knowledge through the use of ontology technology[27]. In a sense, these attempts are aimed at achieving communication across time rather than across organizations.

## 5 Conclusion

This article focuses on ontology because the author believes that ontology helps Japanese organizations to foster cross-organizational communication, which is currently one of their weaknesses. However, the idea of using ontology for the sake of cross-organizational communication is relatively new.

Cross-organizational communication can open up many new possibilities, such as the convergence of technology for innovation creation, more effective high-level processes in software system development, and delivery of business knowledge across generations. For these possibilities to become a reality, there are several challenges to be overcome concerning ontologies, including their intellectual property rights, safe sharing, and the social aspects of the communities supporting them.

In the future, ontologies may also be utilized for man-machine communication. Ontology R&D

and utilization may even lead to a grand challenge to pass the current human knowledge on to later generations and possibly to extraterrestrial life.

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**Glossary**

*1 Unlike other emerging search engines, such as the one developed by Powerset for semantic interpretation of queries, Swoogle mechanically processes the semantic structure of information contained in the documents being searched. Although this is not as "semantic" as human understanding, the technology holds the possibility of achieving equivalent capability.

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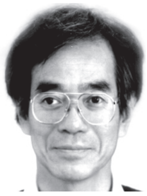

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2

# Considering of Lightning Damage Protection and Risk Reduction for a Safe and Secure Society

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## 1 Introduction

Since ancient times, Japanese culture has considered thunder to be the second most frightening thing (after earthquakes). It does not occur that often in Japan, it is not something the Japanese experience every day. When thunder and lightning do occur, however, lightning strikes can cause major damage such as blackouts, as well as serious injuries to people. For example, in September 2003, lightning struck the National Diet Building. The lightning rods did not function properly, and lightning struck the outer walls and other areas it should not have been able to strike. It also struck the area around the lightning rods on the building's iconic 65m tall central tower, knocking off pieces of granite that fell to the ground.

Of course, various fields to date have addressed lightning countermeasures. Damage to home appliances powered by electricity has decreased. Furthermore, lightning countermeasures both by manufacturers, on the device side, and by power companies, on the supply side, are evolving. The number of power outages due to lightning strikes is decreasing[1]. However, because computer systems are particularly vulnerable to lightning surges[*1], lightning damage to data networks is actually increasing. For example, if lightning causes a mere 20-msec., 30-percent voltage fluctuation, the shock may cause a system to malfunction or lose data. If this happens to a company's or public institution's core computer, it may negatively impact not just a single computer system, but society as a whole[2,3]. With the spread of IT environments, the risk of lightning damage to networks increases every year. The creation of a society with ubiquitous connections may further exacerbate this risk in the future.

Furthermore, there are also recent reports of damage to wind power generation, which is a desirable renewable energy source for the building of a sustainable society[4,5]. Adoption of renewable energy sources is advancing in Europe in particular as a measure against problems such as global warming and petroleum depletion. Because wind and solar power generation rely on nature, there are many issues. Lightning damage countermeasures are therefore essential for the adoption of wind power generation.

This article discusses lightning damage risk, which must not be neglected in the building of a safe and secure society. Narrowing its focus to information technology and wind power generation, the article discusses current conditions and future measures.

## 2 Lightning occurrence and observation

### *2-1 Lightning occurrence*

As depicted in Figure 1, solar heat can warm the ground so that rising air currents form cumulonimbus clouds, so-called thunderclouds. Rising air currents can sometimes grow into tornadoes[6]. At altitudes above 5 km, the air temperature is below freezing, so atmospheric moisture turns into tiny particles of ice. Collisions between these particles generate friction charges, so the upper part of the cloud has a positive charge and the lower part has a negative charge, eventually resulting in an electrical discharge. When the discharge occurs within a cloud or

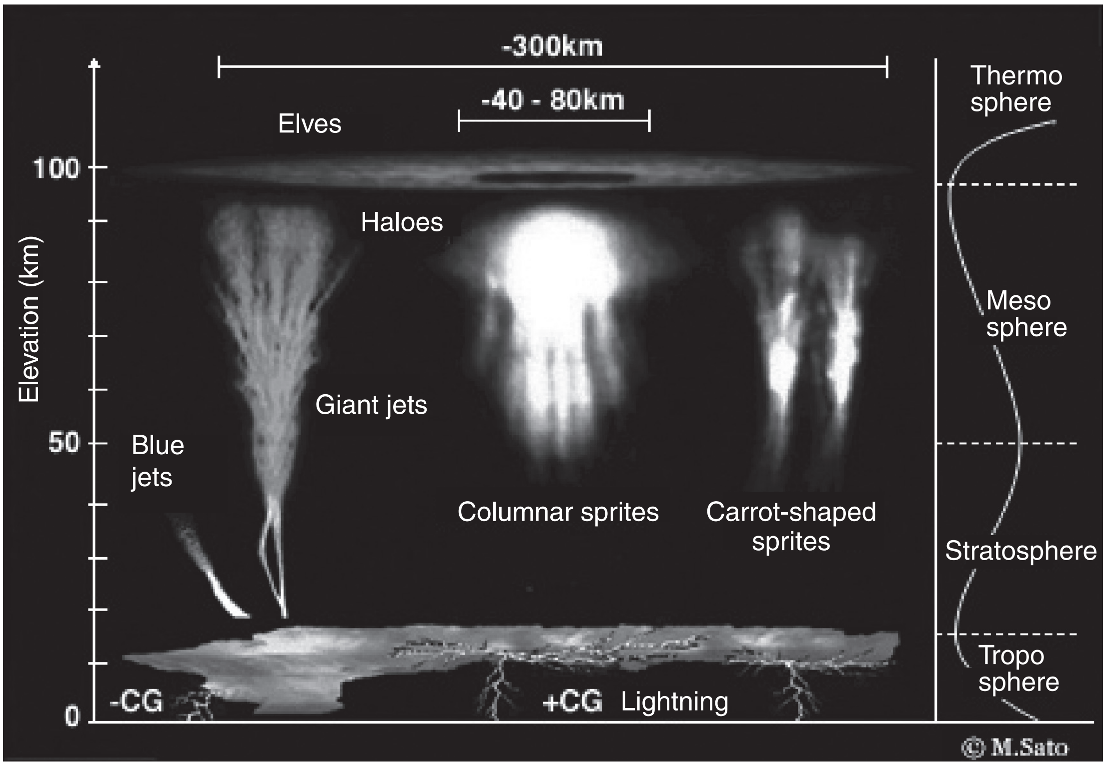


**Figure 1** : Luminescent phenomena high above thundercloud activity (see color chart on cover)

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clouds, it is called cloud-to-cloud lightning. The phenomenon of a discharge powerfully striking the ground is a lightning strike. Lightning can strike anywhere there are thunderclouds, whether they be over oceans, plains, or mountains. Discharges within clouds are called cloud-to-cloud lightning, while discharges from thunderclouds to the ground are called cloud-to-ground lightning (CG). There are four kinds of cloud-to-ground lightning, in combinations of upwards and downwards and positive (+CG) and negative (-CG) polarities. A single lightning strike discharges tens of thousands to hundreds of thousands of amperes and has a voltage of 100 million to 1 billion volts. Converted to electric power, the average is about 900,000 megawatts. Although a lightning strike lasts only about 1/1,000 of a second, research to utilize it as electric power is underway.

In addition to cloud-to-ground lightning generated between thunderclouds and the ground and cloud-to-cloud lightning generated within thunderclouds, lightning can also accompany volcanic eruptions and tornadoes. The length of the discharge path when lightning strikes the ground is several kilometers. Recent research has observed luminescence accompanying discharges that attains an altitude 100 kilometers above the top of thunderclouds[7]. As depicted in Figure 1, ground-based observation and observation using aircraft and Space Shuttles have confirmed three types of discharges (blue jets, sprites*2, and elves) above thunderclouds in the stratosphere, the mesosphere, and the lower thermosphere during cloud-to-ground lightning strikes, mainly those delivering strong positive charges. Discharges occurring above thunderclouds have also been observed to generate $NO_X$ that can cause of acid rain[8], electromagnetic waves, x-rays, and gamma rays. Research into their influence on environmental problems and communications failures is underway. Some theorize that lightning generates 20-30 percent of the world's $NO_X$. Elucidation of lightning and the aurora phenomenon is essential to research on human-induced atmospheric environmental change[9].

Lightning occurs during all seasons, but its nature varies by season. In winter, lightning is common along the Sea of Japan coast and rare more than 35 km inland. It strikes the ground relatively less often than summer lightning, but may occur throughout the day. It is characteristically preceded by snow or hail[10]. The winter lightning that occurs frequently in

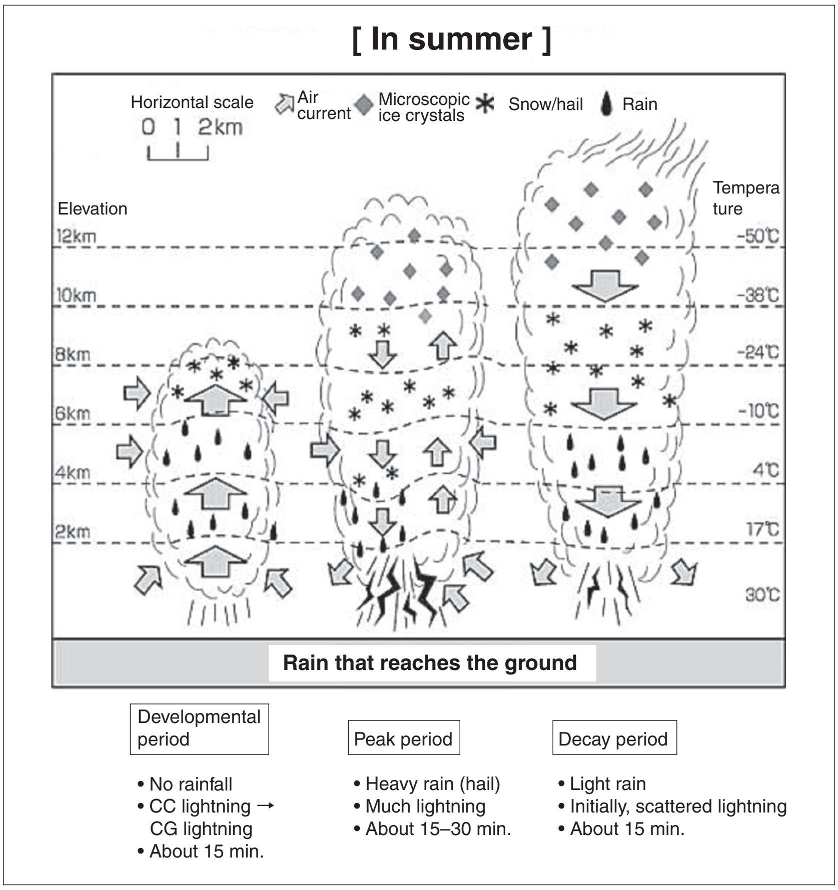



**Figure 2** : Model of the life of a thundercloud[11]

the Hokuriku area is rare in the rest of the world, and it often has a hundred to several hundred times the energy of summer lightning. Figure 2 is a model of thunderclouds, while Figure 3 depicts differences between summer and winter thunderclouds[11].

## *2-2 Lightning observation*

Although the basic mechanisms of lightning generation are understood, there is much that is unclear about the actual behavior of lightning inside clouds. In the future, observation of all lightning by lightning observation sensors located in space is desirable. Observation from space offers the advantages of accurate detection of the altitudes and forms even of lightning inside clouds, as well as a rapid identification of location and direction of movement.

According to statistics collected over the past 10 years, about 500,000 lightning strikes are observed annually in Japan. Currently, power companies and private-sector weather information companies observe the electromagnetic waves generated when lightning strikes and use “lightning location systems” that estimate the location and size of

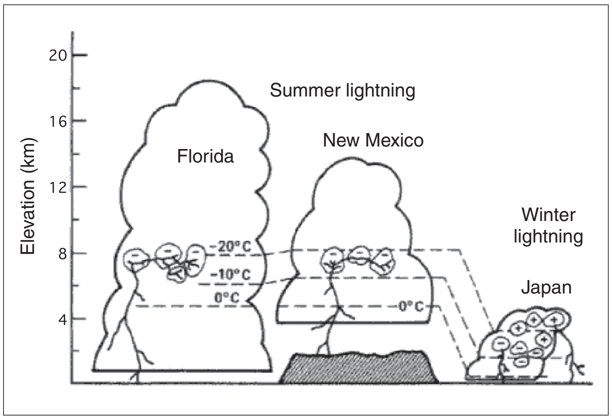
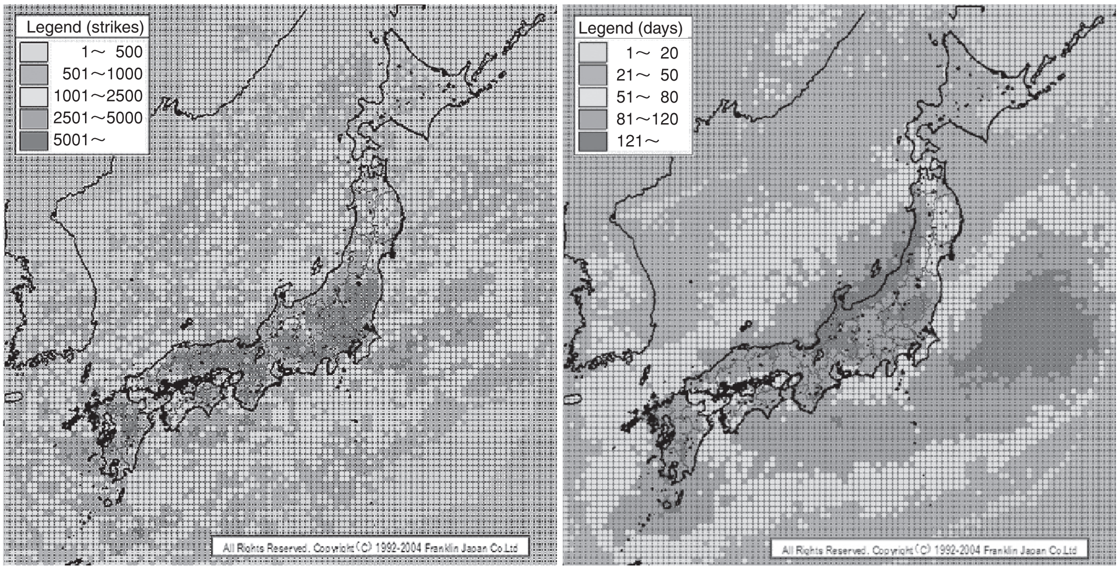



**Figure 3** : Thunderclouds at summer and winter in North America and Japan[12]

lightning strikes to ascertain lightning conditions. They provide information to mitigate or prevent lightning damage. According to these observation data, almost all strikes occur during the summer season (April through October). The above-mentioned winter (November through March) lightning that occurs along the Sea of Japan coast is quite unusual, having been observed only in Japan and Norway where set up measurement equipment.

Figure 4 shows the Japanese archipelago covered with a mesh of 20-km by 20-km squares




(a) Number of lightning strikes (b) Number of days with lightning strikes

**Figure 4** : Map of lightning density and lightning days in Japan (see color chart on cover)

and tabulates lightning strikes within the mesh for the four years from 2000 through 2003. In (a), the frequency of lightning strikes in the major cities Tokyo and Osaka and the surrounding densely populated areas is distinctive. In (b), there is a high number of days on which lightning strikes occur on the Sea of Japan side from Tohoku into Hokuriku. This is because lightning strikes are common during the summer season in the Kanto, Chubu, and Kyushu areas, while during the winter season they are common along the Sea of Japan coast[13]. On the Sea of Japan coast, frequency climbs because of the addition of winter lightning to summer lightning. The area is notable for often suffering lightning damage during the winter as well as the summer[14].

Founded in 1991, the Franklin Japan Corp. has a weather forecast business permit from the Japan Meteorological Agency. It independently gathers information on lightning and weather and provides it to businesses that operate semiconductor factories and golf courses, theme parks, and other recreational facilities. In October 1998, Franklin Japan began operating Japan's first nationwide lightning observation network, the Japan Lightning Detection Network (JLDN). The JLDN networks data obtained from two types of sensors placed in 29 locations around Japan. Based on accurate time data sent by global positioning systems (GPS), it observes lightning strike locations, times, current values, and so on and makes such data available. Power companies have their own similar systems, using the Internet and PHS to provide information on lightning strikes within the areas where they supply electricity.

The Maido 1 satellite scheduled for launch by Osaka Prefecture's Astro Technology SOHLA will use multiple broadband antennas to receive electromagnetic waves from lightning. The plan is to use an instrument called a "broadband interferometer sensor" to determine location, and to predict from space where lightning will occur. This will be the first attempt to use a broadband interferometer in space. If this kind of observation becomes practical, it may enable lightning prediction in obstacle-ridden mountainous areas and over oceans unreachable by terrestrial observation networks. It may also aid in understanding the relationship between torrential rain and global warming[15].

Lightning observation has been underway since 1976 at the CN Tower, the world's tallest tower (553 m), in Toronto, Canada[16,17]. An ordinary power line that is 100 meters tall is struck by lightning about once a year, and the Tokyo Tower (333 m) is struck a few times, while the CN Tower is struck about 60 times every year. With skyscrapers being built in Japan and around the world, lightning countermeasures for tall buildings have become important[18].

### *2-3 Induction of lightning*

It has been about 250 years since Benjamin Franklin experimented with a kite and proved that lightning is an electrical discharge. Based on Franklin's observation, "rocket-induced lightning," where small rockets equipped with wires are launched into thunderclouds to draw lightning to the earth, began in France in the 1970s. Experiments around the world have successfully induced lightning. Research replacing the rocket wires with lasers to draw "laser-induced lightning" to the ground and with water jets for "water-induced lightning" is currently underway. In order to reliably draw lightning to the ground, the ability to discover the location of thunderclouds accurately and the proper timing of rocket launches and so on are important. Accordingly, weather data are essential to this research.

## 3 The state of lightning damage

### *3-1 Damage from direct lightning strikes*

Lightning strikes cause various kinds of damage. In general, there are two types, damage from direct lightning strikes, and induced damage from lightning-generated electromagnetic waves. Table 1 shows types, phenomena, and mortality rates for lightning strikes.

### *3-2 Human injuries*

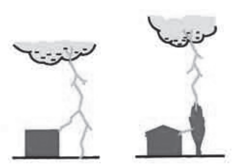
According to data for 1996-2005 in the White Paper on Police, the number of people killed or missing due to lightning strikes per year is 1 to 6 (3.5 annual average). In light of the fact that during the 1960s there was one year in which over 50 people were killed, defensive measures against lightning appear to have become generally disseminated. The primary causes of death from lightning strikes are lightning-induced respiratory arrest and cardiac arrest.

In a recent catastrophe involving lightning, 19 people were killed and 13 injured on April 21, 2005, in Chongqing, China. When lightning strikes a person, the current may travel through the human body (with a high mortality rate), or it may travel mostly along the body's surface before reaching the ground. (The majority of survivors of lightning strikes are the latter type.) Loss of consciousness or paralysis due to lightning strikes often causes death by falls or drowning. When lightning strikes the surface of a sea, people within approximately 20 meters of the strike may be killed or seriously injured. Table 2 shows some examples of damage occurring in Japan and China[19].

### *3-3 Damage to data networks*

Although the more widespread and efficient data network environment of an advanced information society using IT increases convenience and productivity, it is more vulnerable to lightning damage. In recent years, lower voltages are being used in the integrated circuits and other electronic circuits in home appliances and computers. Therefore, damage to

**Table 1** : Lightning strike types and phenomena

| Type | % of strikes | Strike phenomena | Mortality rate if struck |
|---|---|---|---|
| Direct strike | 57% | Most of the current passes through the object struck, so it receives the most damage.<br>• Human/livestock deaths<br>• Destruction of machinery by momentary high-temperature electromagnetic force<br>• A cause of fires<br>• Dielectric breakdown of electrical work | 74%  |
| Non-direct strike | 30% | A discharge path branches off the main lightning discharge path and passes through the object struck, or lightning strikes a tall tree, etc., and separates from the trunk, passing through a person located within a few meters and reaching the ground. Damage is less than with direct strikes. | 90%  |
| Multi-point strike | 13% | Lightning strikes multiple points almost simultaneously, causing multiple injuries and/or deaths. | Averages 1 death per incident |

network devices, shutdowns, malfunctions, and other damage from momentary voltage drops due to lightning strikes and lightning surges that penetrate networks are increasing. Even when lightning does not strike to the somewhere, the electromagnetic waves it generates can cause of electromagnetic compatibility (EMC) in communication lines and electronic circuits.

Figure 5 shows the types of voltage surges and noise that affect electrical devices. Voltage surges exceed the ordinary voltage in electrical circuits or systems. The excess voltage may be momentary or continuous. Voltage surges in electrical devices can cause dielectric breakdown, shutdowns, degradation, and so on. As illustrated in Figure 5, surges are high voltage and low frequency. They may be lightning surges (direct and induced lightning surges) caused by natural phenomena, switching surges caused by transient phenomena in electrical circuit systems, excess

**Table 2** : Examples of locations and situations of damaging lightning strikes in Japan and China

| Date | Location | Site of strike | Damage |
|---|---|---|---|
| 1975/8/5 | Kagawa Pref. | Helicopter | A Self-Defense Forces helicopter crashed after being struck by lightning, killing 4. |
| 1989/8/12 | Shandong, China | Petroleum tank | A storage tank at a petroleum storage facility in Huangdao exploded after being struck by lightning. Several other tanks subsequently exploded. Five dead, 12 missing, 86 injured. |
| 1990/12/11 | Osaka International Airport | Parked aircraft | Lightning struck the ground near the nose of a B-747 parked in parkway spot at Airport. One person working nearby was injured. |
| 1994/8/31 | Gunma Pref. | Train | LightnA storage tank at a petroleum storage facility in Huangdao exploded after being struck by lightning. Several other tanks subsequently exploded. Five dead, 12 missing, 86 injured.ing struck the cockpit at the rear of a parked local train. A conductor was injured. |
| 2000/8/7 | Yamanashi Pref. | Rugby field | Before rain began falling, lightning struck a tree near a rugby field being used by a junior high school team for its training camp. Two players practicing 5–10 meters away from the tree were injured. |
| 2001/7/17 | Shiga Pref. | Biking home from school | A 5th grade student was seriously injured when struck by lightning while biking home from school. |
| 2002/5/24 | Hokkaido | School | Lightning struck near an elementary school's boiler room. A manhole cover in the adjacent kitchen was blown into the air, injuring one food delivery worker. |
| 2003/9/3 | Saga Pref. | On the way home from school | A 4th grader was stuck by lightning on the way home from school and killed. (This was the same day that lightning damaged the National Diet Building.) |
| 2004/7/5 | Okinawa Pref. | Telephone line worksite | Lightning struck the construction site (pedestrian path) of a bridge to an island. A worker installing telephone lines was killed. |
| 2004/7/27 | Nara Pref. | Construction worksite | Lightning struck the worksite for the dismantling of a steel transmission tower, which had been halted because of rain, injuring two people. |
| 2005/4/21 | Chongqing, China | Explosives factory | During a heavy thunderstorm, the emulsification worksite of a civilian-use explosives factory exploded immediately after a lightning strike. The 3-story factory was completely destroyed, with 19 workers killed and 10 injured. |
| 2005/8/23 | Tokyo | Riverbed baseball field | During a rubber-ball baseball game at a riverside ball field, lightning struck the grass about 10 meters behind second base. Two high school students were injured and began hyperventilating for a short time due to shock. There was some blue sky, but distant thunder was heard. |
| 2005/9/10 | Fukuoka Pref. | School grounds | A thunderstorm began during a sports day, so those present took shelter in a gymnasium. When the rain grew light, the festival began again. During a cheering contest, lightning struck the woods next to the sports field. Eight students sitting in the front row of temporary bleachers were injured. |
| 2006/7/14 | Chiba Pref. | Construction area | A thunderstorm became increasingly violent during pipe-laying work in a housing development. Lightning struck just when work was about to be suspended. One foreperson was rendered unconscious and seriously injured, and one worker was injured. |
| 2006/8/8 | Tokyo | Pedestrian | A downpour began one morning, so a person parked his/her motorbike near a 30-meter tree and walked a few meters towards a public restroom when lightning struck the tree. The side strike killed the person. |

Quoted in part from the Aobaya website

voltage caused by malfunctions, and so on. In recent years, there have been reports of people being burned by electromagnetic wave induction generated by lightning. Ordinarily, noise causes electromagnetic compatibility that is lower in voltage and higher in frequency than voltage surges. While it does not destroy light electrical devices such as semiconductors, it can generate enough abnormal voltage to cause fire alarms to malfunction or lose memory, for example[20].

Electric home appliances are not the only items subject to damage. For example, momentary voltage drops at semiconductor manufacturing works and so on that interrupt manufacturing, decreasing manufacturing yield and increasing initial costs, are increasing. Table 3 shows devices frequently damaged by lightning, while Table 4 shows examples of lightning damage in different industries.

Lightning arresters and lightning protection elements for industrial and home use have been developed and are sold, but there are no complete technologies that avoid from lightning. Although improvements to communications devices such as fax machines have made them less susceptible

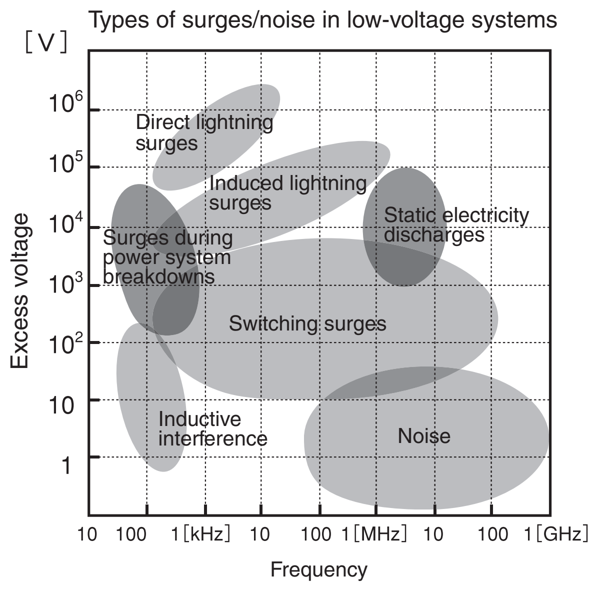



**Figure 5** : Types of voltage surges and noise

Provided by Otowa Electric Company, Ltd.

**Table 3** : Devices frequently damaged by lightning

| Devices frequently damaged by lightning | Subject equipment |
|---|---|
| Devices with separate bodies and terminals | Surveillance cameras, disaster prevention equipment, entry/exit gates, factory control equipment, hot water heaters, air conditioners, etc. |
| Communications devices and network equipment | Office buildings: not only transponders and switching equipment, but also many network terminal devices, etc., connected to power and communications lines<br>Homes: multifunction telephones, fax machines, modems, PCs, cable TV terminals, etc. |
| Communications equipment with antennas | Wireless relay stations, broadcast equipment, wind power generation control equipment, etc. |

**Table 4** : Examples of lightning damage in different industries[21]

| Cost per strike | Industry | Type of damage |
|---|---|---|
| Human life | Petrochemical plants, explosives industry | Human lives are endangered because they frequently deal with dangerous explosives. |
| 10s of millions of yen to 100s of millions | Steel | Problems can occur across a wide range of processes, mainly from control systems to rolling. Diverse processes mean losses are high. |
| Millions of yen to 10s of millions | Semiconductor industry | Because there are many processes that are extremely sensitive to voltage changes, momentary drops can cause damage. |
| 100s of thousands of yen to millions | Fiber, chemical film, printing, machining, surface processing, software development, waste incineration | Momentary voltage drops cause variations in the quality of manufacturing materials. If not detected before final processing, major losses can result, which is the same as for film application in the micron order processes.<br>In software development, momentary voltage drops can destroy data, causing serious damage.<br>Processes using blast furnaces for high-voltage processing can be seriously damaged by power outages. |
| 10s of thousands of yen to 100s of thousands | Food, unmanned communications bases, water and sewage monitoring sheds, hospitals | Electronically controlled processing, especially rice cooking and baking, which use many electronic devices, suffer losses (defective products) due to voltage drops. Unmanned communications bases are equipped with backup systems such as emergency power, but they often suffer damage to communications and control systems. |

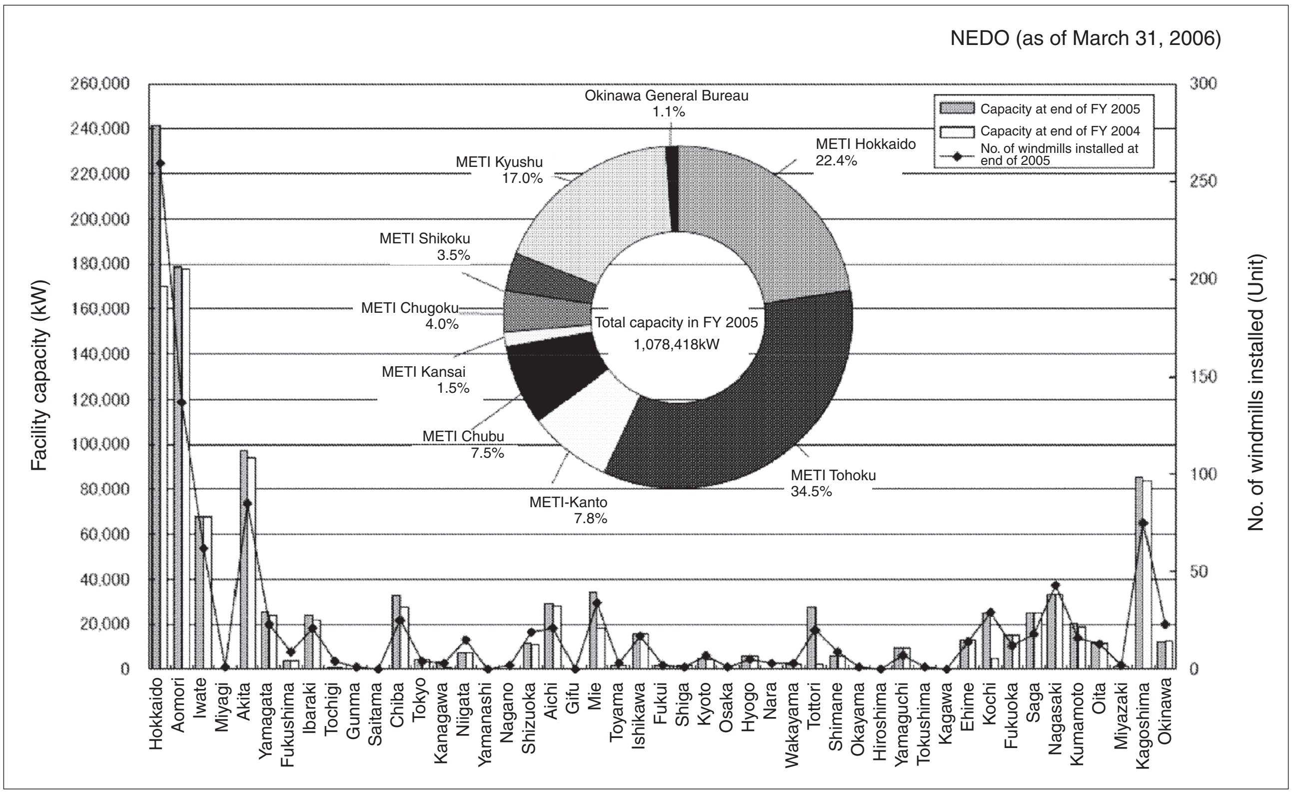



**Figure 6** : Adoption of wind-generated power by prefecture[24]

to lightning damage, because lightning surges are current-carrying, lightning surge current flows to the protective devices on the telephone line side, which can destroy terminal adapters and routers. Furthermore, if devices such as outlets where ground terminals for surge protection are bare happen to be touched when lightning strikes, there is danger of electric shock[22]. The cost of adopting lightning damage countermeasures should be determined in light not only of repair and replacement costs, but of lost profits as well[23].

### *3-4 Damage to wind power generation systems*

Conventionally, lightning damage has mainly been to home appliances and telephones, and power transmission and generation equipment malfunctions and damage due to strikes on power lines. With the adoption of wind power generation equipment, however, lightning damage is also increasing in this area. The construction of tall structures for wind power generation or other purposes changes the surrounding environment and can increase the number of lightning strikes. In the case of Canada's CN Tower, damaged number by lightning increased doubled than before. In this way, the increasing installation of wind power generation equipment is causing problems not found in other countries due to Japan's particular weather conditions. Damage to wind farms from winter lightning on the Sea of Japan side is one example. Figure 6 breaks down by prefecture the adoption of wind power generation. Hokkaido and the Tohoku area have the most wind power generation sites.

The winter lightning on the Sea of Japan side occurs along the coastline all the way from western Hokkaido to the Sanin region. There is lightning on 30 to 40 days per year. This area currently has 46 wind power generation sites, of which 23 have received lightning damage at some time. Of these, 8 have steel towers for lightning protection. Although steel towers can be effective in the event of a lightning strike, lightning rods are not 100-percent effective. Depending on the magnitude of the lightning current, mechanical effects in addition to heat effects such as temperature increases in electrical circuits and melting from arcs have been observed. Simulations indicate that the mechanism in such cases is expansion and contraction from sudden overheating on the discharge path, which

**Table 5** : Damaged windmills by component (unit: %)

| Damaged component | Denmark | Germany (450 kW and up) | Sweden (450 kW and up) |
|---|---|---|---|
| Blade | 10 | 35 | 43 |
| Power system | 20 | 20 | 22 |
| Control system | 51 | 36 | 18 |
| Mechanism | 7 | 4 | 4 |
| Other | 12 | 5 | 13 |

causes supersonic pressure waves to spread to the surroundings, generating impact pressure. Furthermore, unlike summer lightning, winter lightning is not necessarily a momentary current, but instead is sometimes a large current flowing for a certain amount of time with a very large amount of energy. Therefore, the energy from lightning strikes apparently can react with steam on windmill blades to cause explosions that damage the equipment. One windmill blade was struck more than 100 times in a single year by winter lightning in Japan. In addition, repair costs over five years for lightning strikes on some windmills equaled the original construction costs.

In recent years, windmills have become markedly larger. The height of the blade tips on many of these large windmills is over 100 meters, which increases the frequency of damage from lightning strikes. Damage to the blades of large windmills have higher repair costs and require more time for replacement (including transport and installation). The increase in windmill downtime has brought about a decrease in the operation rate and utilized capacity of windmill equipment[24].

In Europe, where wind power generation is being aggressively adopted, the effects of lightning on wind power generation equipment have been monitored since 1990 in Germany, Denmark[25], and Sweden. On flatlands over the past 10 years, lightning strikes have damaged 8 percent, 3.9 percent, and 8.5 percent of the respective countries' turbines. In hilly country, lightning has damaged about 15 percent of turbines. The cost of the damage reportedly averages about 300,000 yen per strike[26]. Table 5 shows statistics for lightning damage to windmills by component for Denmark, Germany, and Sweden[27].

## 4 Lightning damage ountermeasures

### 4-1 Measures for indoor and outdoor wiring

Lightning surge currents enter homes and buildings via the routes shown in Figure 7. Measures to protect those routes are therefore necessary[23]. In light of the characteristics of lightning, the important functions of surge protection equipment are the ability to tolerate large surge currents, with construction that will not allow fires to start, and the ability to withstand induced lightning several times. There are numerous products on the market for lightning protection. The main types are called varistors and arresters. They cause lightning surges to flow into external grounds to protect connected devices.

### 4-2 Prediction from weather data

The Japan Meteorological Agency's daily weather forecasts predict lightning with the expression "accompanied by lightning in some places." Furthermore, it only issues "lightning advisories" rather than "lightning warnings." This is because it is difficult to predict the occurrence of lightning with a high degree of accuracy. Current forecasting technology can predict the potential formation of the cumulonimbus clouds that generate lightning, but cannot predict locations or times with high accuracy. Moreover, even when cumulonimbus clouds form, it is very difficult to tell in advance whether they will be the type of cumulonimbus clouds that generate lightning or those that do not. Under these circumstances, forecast periods can be divided into three types depending on the targeted time period, "nowcasts," "short-time forecasts," and "short-range forecasts," with appropriate methods for each. Table 6 shows the forecast periods and methods for each type. In addition to these methods, research to predict lightning with greater accuracy is also underway. One new method being researched is numerical forecast models on a short-range scale. In order to raise the accuracy of lightning

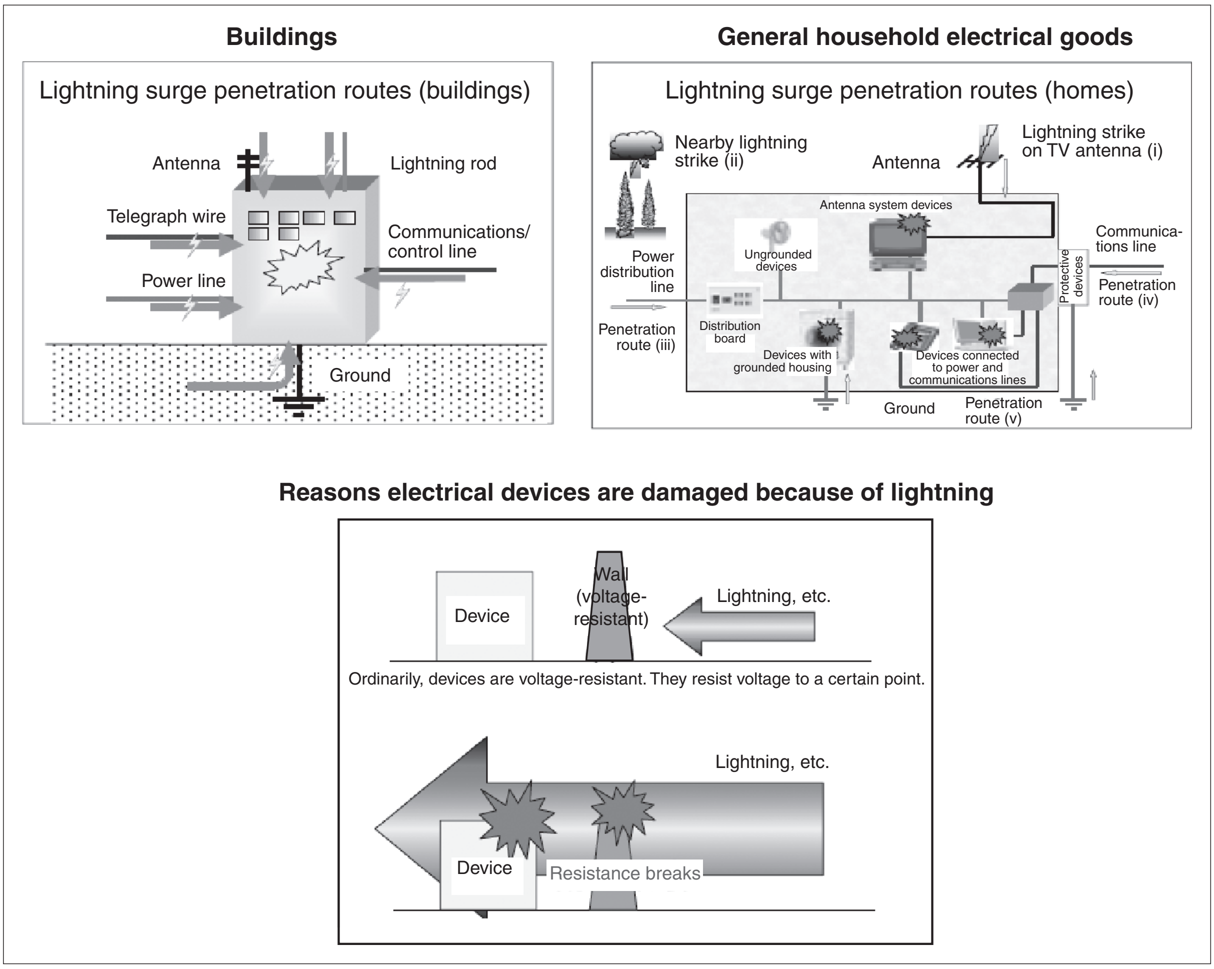



**Figure 7** : Lightning surge penetration routes

Quoted from Tokio Marine and Nichido Risk Consulting Co., Ltd. RISK RADAR No. 2004-4

**Table 6** : Lightning forecasting targets and goals

| Type | Target time period | Goal |
|---|---|---|
| Nowcast | Forecast a few minutes to 10 minutes ahead | After cumulonimbus clouds form, assesses the signs of lightning generation and forecasts lightning. Requires frequent observations and a swift transmission system. |
| Short-time forecast | Forecast a few 10s of minutes ahead | Regarding thunderclouds with observed lightning, forecasts their movement and approach. Forecasting quickly forming or transient thunderclouds is difficult. |
| Short-range forecast | Forecast several hours to 2 days ahead | Based on results of numerical forecasts, produces indices such as air stability with possible relationships to lightning generation and forecasts the potential of lightning generation. |

prediction using numerical forecasting models, the development of various technologies and knowledge, such as accumulation of lightning observation data, understanding of lightning-generating mechanisms from those data, and greater precision in the models and in surface imagery, is essential. Furthermore, not only the Japan Meteorological Agency, but also local power companies and weather-related businesses also actively issue information and forecasts related to lightning[28].

### *4-3 Measures for wind power generation equipment*

Lightning-strike damage to the blades of wind power generation site consists of delamination or burning of surface composite materials and heating or melting of metal components (receptors and conductors) at the point of the strike. Blade damage occurs when a lightning current is conducted through composite materials or between their layers, and the shockwaves thus generated follow the blade's edges, tearing or bursting the blade's surface from the inside. The greatest damage occurs when lightning causes an arc discharge inside a blade. Blade damage follows many patterns, ranging from surface cracks to complete destruction. Improving materials is an effective countermeasure against this phenomenon. When lightning damage occurs, the destruction behavior of the materials is complex and the mechanism is difficult to ascertain. However, improved plastics reinforced with fiberglass or carbon fiber have a number of outstanding characteristics that cannot be obtained from a single material, so their use in blades is common.

Of course, surveys of the locations of wind power generation machinery are also important. The New Energy and Industrial Technology Development Organization (NEDO) is constructing a database on wind conditions[29].

## 5 Lightning countermeasures that should be considered

### 5-1 Database construction and accurate forecasting

The ability to forecast lightning strike locations in advance would simplify the prevention of lightning damage. This requires an understanding of the dynamics inside thunderclouds to clarify the distribution of charges. Furthermore, it is necessary to measure the progress of discharges using systems that combine radar and interferometers and to pursue research on lightning discharges. Regarding observation, observing lightning from space will enable scientific elucidation of the correlation between lightning activity and global warming. This will require cross-sectoral research spanning electrical engineering, meteorological engineering, and space engineering.

Because the occurrence of lightning varies by season and location, countermeasures specific to local characteristics are necessary. For example, the difference in current between weak lightning and strong lightning is a factor of 100. Countermeasures that address intermediate lightning will not work against strong lightning. Currently, users must estimate what countermeasures they require when selecting equipment, so in many cases lightning countermeasures are incomplete.

The Japan Meteorological Agency does not make public data on the number of times lightning occurs. With the current observation system and technology, lightning occurrence, which is a local weather phenomenon, is observed relatively accurately. Yet because prediction is difficult, the Agency does not issue the above-mentioned “lightning warnings.” More accurate forecasting and the dissemination of information transfer are necessary for the prevention of lightning damage.

Power companies are aware of how many power outages are caused by lightning, but they are not aware of all lightning damage. It is therefore necessary to collect the data that are presently scattered and create an environment that makes it easy for users to select lightning damage countermeasures. Furthermore, because prompt transmission of lightning information is essential in order to prevent damage to ordinary people, the construction of networks is also an issue. In order to combine the data held by individual companies and build conditions for easier forecasting, private-sector technical development and further promotion of forecasting services are necessary.

### 5-2 Interagency cooperation and legal development

Lightning current penetrates facilities and homes by various routes, and different government agencies have jurisdiction over the different routes. The Ministry of Internal Affairs and Communications oversees communications, while the Ministry of Economy, Trade and Industry handles electric supply equipment, and the Ministry of Land, Infrastructure and Transport is in charge of lightning rods. This makes it difficult to create comprehensive standards for countermeasures. The creation of measures that span agency boundaries is necessary.

The JIS standards for prevention of lightning damage in Japan are based on standards created during the 1940s. Although they have been steadily upgraded recently, they are not adequate for high-rise buildings or for networks. As the information society advances, the standards must be revisited.

### 5-3 Initiatives at the design stage of structures

Recently, construction of high-rise buildings is advancing in the Tokyo metropolitan area in particular. An increase in damage to buildings from direct lightning strikes has accompanied this. For example, on July 22, 1999, lightning struck an exterior wall of the Tokyo Metropolitan Government building. An approximately 20 cm × 20 cm, 10-cm deep piece of the exterior wall on the northwest corner of the 41st floor (about 180m above the ground) broke off. The roughly 400g chunk of rock was found on the pedestrian walkway on the north side of the building. Measures against this kind of accident are also necessary.

With favorable wind conditions common in areas along the Sea of Japan coast, introduction of wind power generation site is being encouraged. For the purpose of risk avoidance as well, a survey of nationwide windmill damage from lightning strikes, measurement of winter lightning and collection of data on its characteristics, creation of a comprehensive lightning strike map based on these efforts, and compilation of guidelines for lightning protection measures are necessary. NEDO is currently working on a project that began in 2005 to "survey lightning countermeasures for wind power generation site". NEDO is engaged in another project that "aims to set guidelines for Japanese-type airflow power generation" since this project began in 2006. However, despite these initiatives, lightning-strike damage is still occurring. Into the future, creation of detailed diagrams of the relationship between lightning-prone areas and structures, reexamination of the economics of wind power generation site, and research on technology resistant to lightning damage are necessary. Furthermore, the New Tokyo Tower will building in Japan that will stand 610m tall, so it will likely be struck by lightning about as often as Canada's CN Tower is now. If broadcast equipment is damaged by lightning, it could cause long-term problems for information transmission in the Kanto region. Elucidation of the phenomenon of lightning strikes on high-rise structures and the devising of countermeasures are urgent tasks.

Wind power generation turbines stand about 100m height, yet there are data that indicate they are struck by lightning more frequently than power transmission towers of the same height. To resolve this matter, about 220 scientists from 18 countries, mainly in the EU, involved and began working on the five-year COST Program at the end of 2005. The program aims to investigate how the amount of $NO_X$ generated by lightning, electromagnetic damage, natural disasters, and so on are changed by wind power generation equipment. Since the project is related to understanding where to locate wind power generation sites, which are flourishing in Japan, and mechanisms for mitigating natural disasters, Japan's active participation is desirable.

### 5-4 Response to overseas standards

Standards for lightning damage countermeasures in the International Electrotechnical Commission (IEC) 61400-24 international standards for windmills are based on damage to conventional American and European wind power generation equipment (i.e., windmills with blades of 20m or less) and set forth cross sections for areas prone to lightning and for conductors. Data collection and evaluation of actual cases are therefore necessary for large-scale wind power generation equipment and lightning with greater energy (e.g., winter lightning).

Overseas, many buildings are connected to grounded communications and power lines, so lightning surges do not cause potential differences between them. Under the IEC standards, malfunction tests are performed at several kV. When foreign products that meet this standard are used overseas, there is no problem, but in Japan, where separate grounding is common, a lightning surge of about 20 kV will easily destroy them. In Japan as well, the method of grounding individual buildings to make them equipotential was adopted in the 2003 revision of the Japanese Industrial Standards (JIS) as "lightning protection for structures." However, it is feared it will take years before that grounding method is widely disseminated.

In Japan as well, wind power generation equipment is spreading as a form of renewable

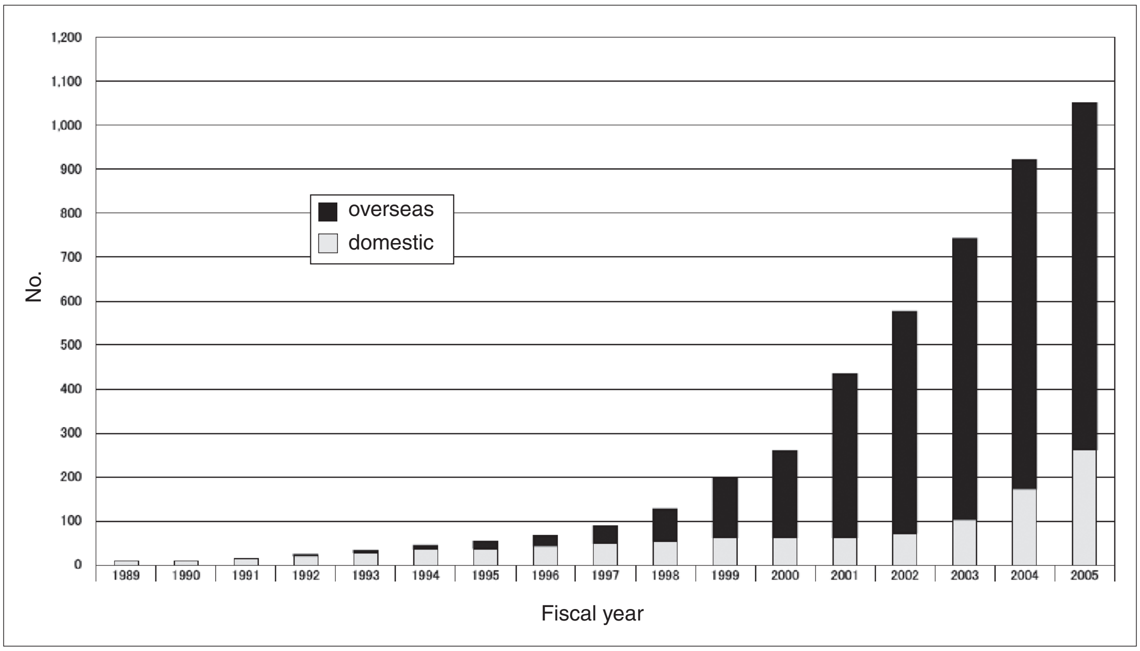



**Figure 8** : Number of foreign and Japanese windmills installed at wind power generation sites

energy, but there is concern in this sector as well regarding the issue of separate grounding. As can be seen in the graph showing the rate of adoption for foreign and Japanese equipment in Figure 8, use of foreign equipment is growing. Equipotential grounding should be required when foreign equipment is adopted[30].

### *5-5 Development of personnel involved with high voltage*

The fostering of human resources related to high voltage is another important issue. This is a shared issue among developed nations. Lightning is taught almost entirely in electrical engineering, especially in high-voltage engineering. Even though the electrical engineering sector has a good employment rate, in recent years it has been unpopular with students, who show little interest in the field. Furthermore, the criteria for establishing a university department of electrical engineering no longer include the obtaining of certification as an electrical chief engineer. Most universities therefore have decreased their courses for this form of certification. There is a danger of not being able to train sufficient personnel at universities to work in the high-voltage field. At the pre-university level as well, there are already problems with elimination of university courses on high voltage and with developing successors to the present generation of engineers.

It is necessary first to highlight the importance and fascinating aspects of energy and to generate interest among students. Energy education is important not just for high school students, but for elementary school students as well. It is necessary to build frameworks to enable the Japanese people to appreciate the importance of energy. Relevant academic societies such as the Institute of Electrical Engineers of Japan must take the lead on efforts spanning industry, academia, and government.

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**Glossary**

*1 Surges in current generated by lightning;

called "induced lightning."

*2 A luminous phenomenon that occurs in the mesosphere above thunderclouds. It is a completely different phenomenon from lightning, but is believed to be associated with lightning (lightning discharge). In recent years, it has been observed by satellites (such as the ROCSAT-2 equipped with an ISUAL imager).

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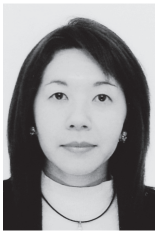

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3

# Analysis of Japan's Nanotechnology Competitiveness — Concern for Declining Competitiveness and Challenges for Nano-systematization —

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## 1 Background and issues

Japan is generally believed to be strong in nanotechnology, but is it true?

The beginning of the promotion strategy for the nanotechnology and materials field in the "Third Science and Technology Basic Plan"[1] states, "Japan's materials technology, because of decades of unstinting effort and research by many researchers and research organizations, is firmly established at the world's highest level for all stages, from basic to applied research to practical application of raw materials and component materials, making them the source of the global competitiveness of Japan's domestic manufacturing." This statement, however, applies to materials technology alone. Although the strategy states that nanotechnology ("nanotech") is also at the world's highest level, it says, "the source of Japan's strength in nanotechnology is its strength in materials technology." Some perceive that the strong materials field drives nanotech, rather than the entire nanotech field itself being strong. Focusing on nanotech alone, an increasing number of nanotech experts are experiencing a sense of crisis or a feeling of being stymied regarding Japanese nanotech.

Where do these experts' feelings come from? And on what basis can one claim that Japan is strong in nanotechnology in the first place? Based on research papers, patents, and survey results, this article intends to discuss, by examining nanotech's technological characteristics and industry structures, Japan's nanotech competitiveness and changes in the competition stages of nanotech, which are both difficult to grasp through quantitative analysis alone. Although an examination of factual data on research papers and patents may suggest that Japanese nanotech is in a superior competitive position, the country is likely to face serious problems in the future when nanotech undergoes full-fledged commercialization and its stages of competition shift. The authors address these issues by centering around the term "systematization."

Recently, nanotech has generally been defined as technology dealing with scales from 1 to 100 nanometers. In the above-mentioned promotion strategy for the nanotechnology and materials field, the nanotech that should be promoted by the national government is "technology that breaks away from traditional principles or conventional wisdom to open up new worlds of science and technology, enabling not only dramatic advances but also potentially strengthening industrial competitiveness and creating new industries[1]." In this context, the strategy calls the nanotechnology meeting such criteria "true nano." The strategy further states that where nanotechnology is technology that aims to utilize phenomena and characteristics whose expression is peculiar to the nano world, "true nano" is defined as a kind of nanotechnology encompassing the following:

- Creative R&D expected to bring discontinuous progress (jump ups) rather than extensions

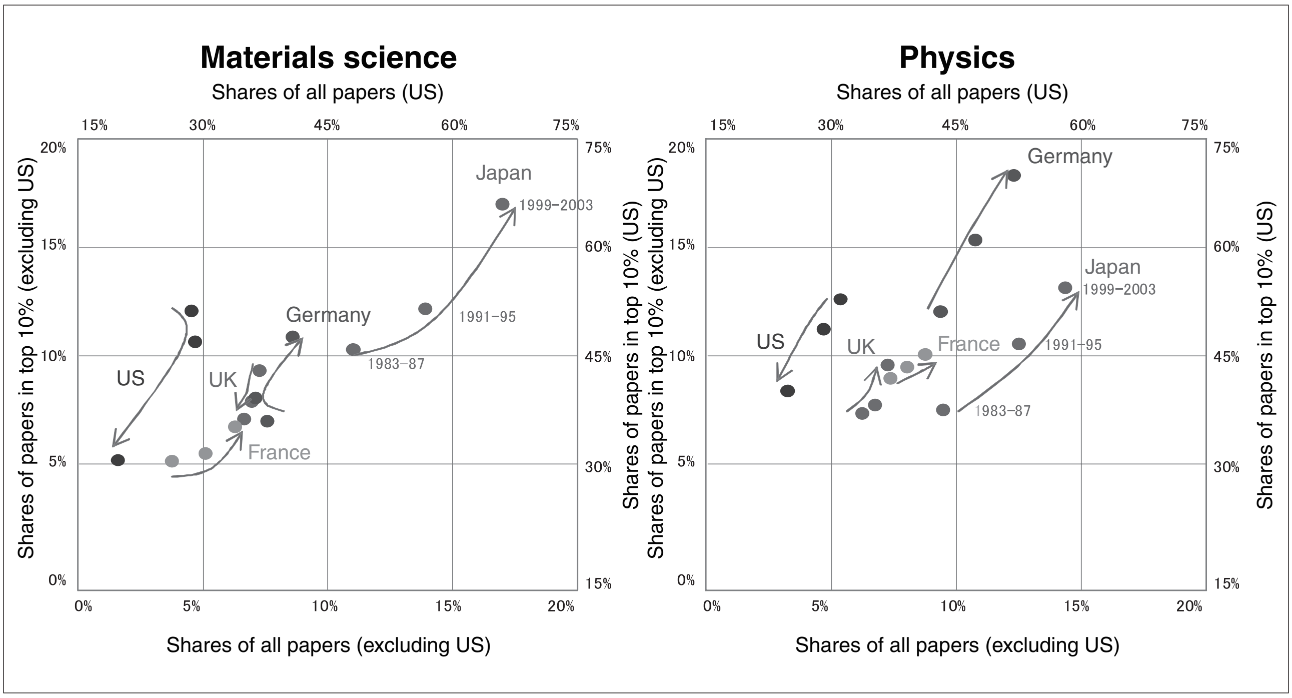


**Figure 1** : Materials science and physics papers as a share of all papers and of papers in the top 10% in major countries over 20 years[2]

of conventional technology, and,
- R&D with a great potential for significant industrial applications.

In other words, future nanotech is not merely the extension of miniaturization technology below the 100-nm level, but instead is nanotech that will help create new industries and strengthen industrial competitiveness. This report adopts the same definition of nanotech.

## 2 Quantitative analysis of elemental science and technology: based on papers, patents, and Delphi survey

### 2-1 Analysis of research papers

It is difficult to quantitatively analyze nanotech research results from papers. Nanotech is an interdisciplinary field, and with the exception of recently-started journals such as Nature Nanotechnology, there have been no journals specializing in the nanotech field. Analysis of recent nanotech journals alone will thus not provide data sufficient in terms of quality or quantity*1. In order to find the results of basic research in nanotech, the authors therefore turned to materials science and physics because of their strong characteristic as fundamental disciplines of nanotech.

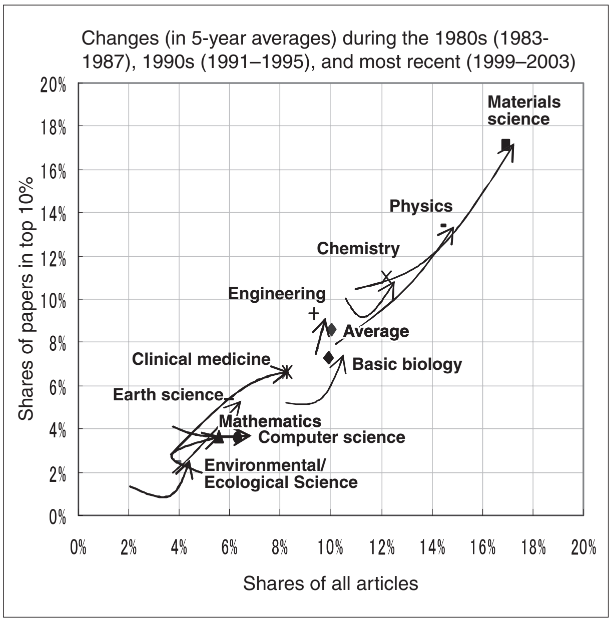


**Figure 2** : Papers in various fields as a share of all papers and papers in top 10% in Japan over 20 years[2]

1. Basic biology includes agriculture, biology/biochemistry, immunology, microbiology, molecular biology/genetics, neuroscience/praxeology, pharmacology/toxicology, botany/zoology.
2. The bottom end of the arrow indicates the 5-year average for 1983–1987; the point indicates that for 1999–2003.

Based on analysis of research papers in materials science and physics, Japan is next behind the leader US in terms of both total number of research papers and the top 10 percent most-cited papers, with exception of the top 10 percent most-cited papers in physics, and the gap is narrowing every year. (See Figure 1.) In materials science in particular, Japan is well ahead of all other countries except the US. Looking at various fields in Japan as well (see Figure 2), Japan's strength in chemistry as well as in materials science and physics is apparent.

## 2-2 Analysis of patents

The patent application situation of various countries can be found through keyword searches related to nanotech and its applied technologies. The authors classified patents according to the nationalities of applicants for patents submitted to four major patent offices: the Japan Patent Office, the US Patent and Trademark Office, the European Patent Office, and the World Intellectual Property Organization (WIPO). Figure 3 shows a comparison of applicant nationalities in 2003-2005 for the 10 countries with the most applications[4-5]. In 2005, there were approximately 6,700 US nationals, the highest number, with Japan second at about 4,200, with all other countries well behind. Looking at changes over time, both Japan and US nanotech-related patents are increasing significantly.

In 2005, however, three of the top five organizations applying to the Japan Patent Office were public research institutions[4].

## 2-3 Japan's R&D level according to a Delphi survey

In 2004, a Delphi survey conducted by the National Institute of Science and Technology Policy asked specialists in individual science and technology disciplines to rank Japanese research and development versus the US, Europe, and Asia in one of five levels from "leading" to "behind"[6]. Figure 4 shows the results versus the US and Europe. The numbers in the axes of the chart represent the values numerically indexed from the responses received for the five levels. The survey specifies 10 areas of emphasis*2 in the nanotech/materials field. Almost all these areas

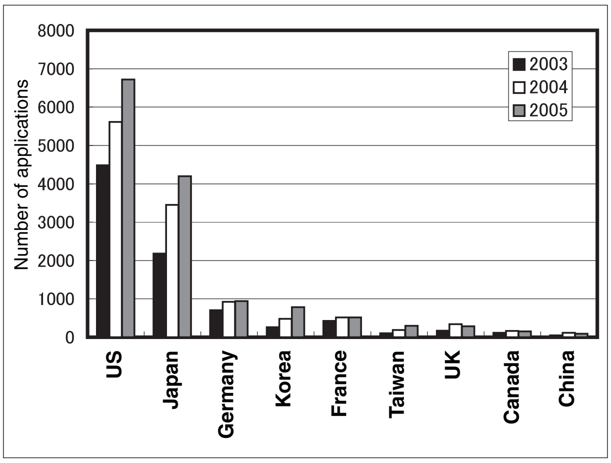


**Figure 3** : Nanotech patent applications submitted to the four major patent offices [JPO, USPTO, EPO, WIPO], by nationality

Prepared by the STFC based on References[4,5]

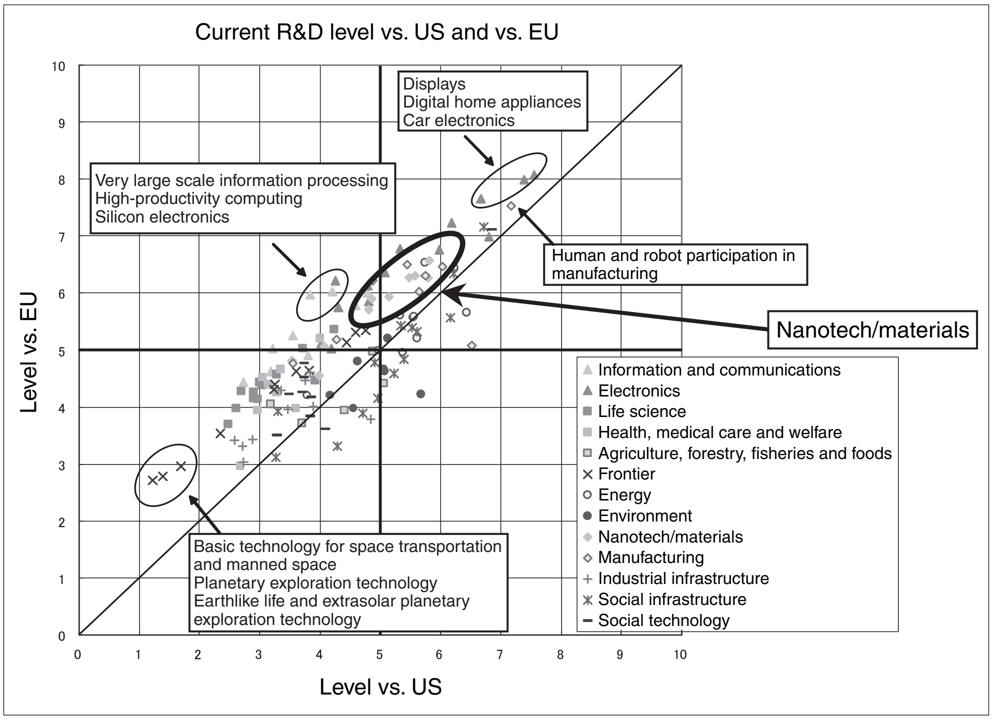


**Figure 4** : Japan's R&D level according to Delphi survey[6]

are located in the center of the chart or slightly higher. In other words, the level of Japanese nanotech/materials development is seen as somewhat leading or even with that of the US and somewhat leading that of EU countries.

### 2-4 Potential of Japanese nanotech as revealed by quantitative evaluation

The above results confirm to some extent the stereotyped view that "Japanese nanotech is strong." These data, however, may demonstrate that Japan's strength lies in individual nanotech areas. In this sense, one can say that Japanese nanotech has great potential. With some exceptions, however, the technical seeds of nanotech have not been commercialized. From the perspective of technology, it may therefore be premature to evaluate the international competitiveness of nanotech as a whole. Beginning in the next section, the authors discuss the potential of Japanese nanotech, focusing on the competing technical areas and their changes that nanotech R&D will probably face in the future.

## 3 Technical characteristics of nanotech and challenges for nano-systematization : facing increasing technological uncertainty

### 3-1 Outlook for nanotech R&D in the future

Figure 5 shows nanotech technical levels and times to commercialization as described by M. Roco, who has spearheaded the National Nanotechnology Initiative (NNI) in the US[7]. This chart depicts progress beginning with the first generation: passive nanostructures expressing previously unknown functions as a result of improving microfabrication technologies for conventional materials. The second generation is active nanostructures gradually expressing new and original functions at the nanolevel that affect other materials and systems. In the third generation, these new nanolevel functions become original systems expressing new mechanisms. Finally the fourth generation is nanosystem materials designed at the atomic or molecular level as molecular devices in which nanolevel molecules express their intrinsic functions*3. Technology examples in the first generation include coatings, nanoparticles, and nanostructured metals. In the second generation, they include targeted drugs, environmentally adaptive structural materials, and actuators. Third-generation technology examples include three-dimensional network structural materials and supermolecule materials. In the fourth generation, technology examples include molecular devices designed at the atomic or molecular level as nanosystems.

### 3-2 Technical characteristics and challenges: from top-down technology to bottom-up and nano-systematization technology

Figure 5 presents possible challenges that nanotech should tackle. As is often said, research in physics, chemistry, and materials science in the US targeted nanolevel problems long before the Federal Government began promoting nanotech. However, they were merely handling bulk materials, "aggregate" that included nanoscale structures. Although scanning tunnel microscopes (STM) and self-organization technology have recently enabled some extent of molecular-level control, perfect control and assembly at the nanoscale level remains problematic. Here is where the true challenge of nanotech awaits. Structures designed and systematized at the molecular level could become materials completely different from conventional materials in terms of functions and characteristics. This is called "the technological uncertainty of nanotech."

Conventional technological uncertainty is understood to be a phenomenon where miniaturization approaches physical limits, with quantum effects appearing. The technological uncertainty of nanotech, on the other hand, is a situation in which one is completely unsure how to assemble structures designed and systematized at the molecular level, or what kind of functions such nanosystem materials might express if they were assembled. Taken to the extreme, an infinite number of microstructure materials and corresponding assembly and control technologies are conceivable, theoretically resulting in an infinite number of potential nanosystems.

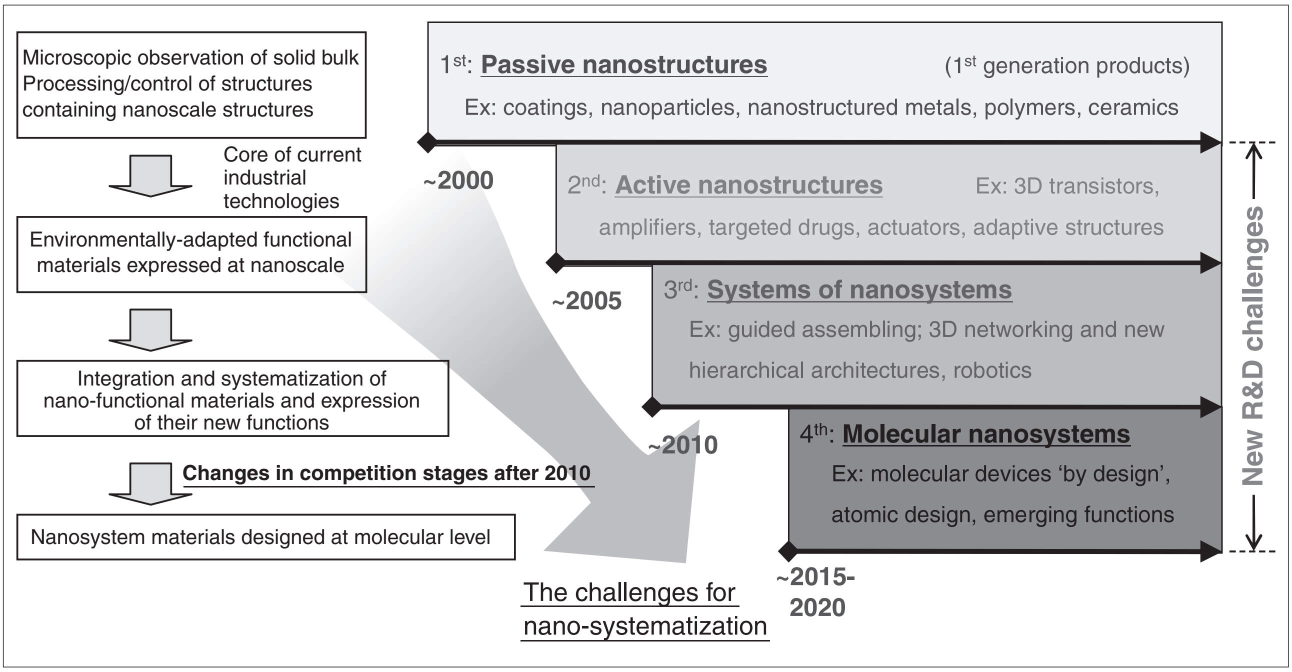


**Figure 5** : Roadmap for nanotech development

Prepared by the STFC based on Reference[7]

**Nanotechnology and nanoscience**

Conceivable categories of nanoscience include measurement of unknown properties of existing substances (e.g., measurement of electrical conductivity, temperature dependency, etc.), structural analysis of new materials and elucidation of the interdependency of new materials, and development of computation methods for nanosimulation. With "nonlinear model-based" R&D becoming the mainstream today, mutual feedback between nanotechnology and nanoscience is extremely important. Nano-systematization discussed in this article is more closely associated with technology than science because of its significance in the context of commercialization. However, because of the technical complexity of nanosystems, nano-systematization will inevitably need support and feedback from nanoscience.

In the nanotech field, the former type of technological characteristic centered on miniaturization is generally called top-down technology, while the latter, which aims to fabricate nanosystems, or to achieve nano-systematization, is called bottom-up. In other words, technical development that aims to improve materials function through repeated scaling down to break through conventional technological issues is considered top-down technology, while technical development that aims to fabricate nanosystems from nanofunctional materials that are to be ultimately designed at the molecular level is considered bottom-up technology. Since these classifications have been discussed in past issues of "Science and Technology Trends"[10-11], this article will not go into detail, but they are completely different from the terms "top-down" and "bottom-up" as used in fields such as economics[*4].

The technical challenges for nanotech are now shifting from top-down to bottom-up technology focused on nanosystem materials development. Bottom-up technology will not bring significant benefits to industry unless it is systematized as functional materials. Both kinds of technology include characteristics of the "true nano" described in Chapter 1, but bottom-up technology carries greater expectations for radical progress and the creation of new industries because of its innovativeness and discontinuity. Accordingly, the next section will discuss Japanese competitiveness in both technologies.

**Table 1** : Delphi survey results on nanotech/materials R&D levels

| | Areas included in the nanotech and materials field*1 | vs. US*2 | vs. EU*2 |
|---|---|---|---|
| Bottom-up | Nanomaterials modeling simulation | 4.06 | 5.07 |
| | Nanobiology | 3.53 | 4.82 |
| | Nano devices and sensors | 4.81 | 5.72 |
| | NEMS technology | 4.85 | 5.90 |
| | Matter and materials origination, synthesis technology, and process technology | 5.58 | 6.31 |
| | New materials from nanolevel structure control | 5.47 | 6.28 |
| | Nano measurement and analysis technology | 5.15 | 5.94 |
| | Environmental and energy technology | 5.80 | 6.27 |
| Top-down | Nano process, molding, and manufacturing technology | 5.82 | 6.56 |

*1: "Nanoscience for a safe and secure society" (vs. US: 3.98) is excluded because of the difficulty of technological evaluation
*2: Indexed with equality at 5.0

Prepared by the STFC based on Reference[6]

## 4 Changes in the competition stages of nanotech, and Japan's strengths and weaknesses

This section considers Japan's nanotech competitiveness in top-down and bottom-up technologies as discussed in the previous section. Here, this article again addresses the results of the Delphi survey that provides a holistic overview of future science and technology. After examining the details of Japan's R&D level, the article considers venture corporations, which increase in importance every year in their roles in developing technologies and in some cases commercializing them as well.

### *4-1 Relationships between Japan's strengths and weaknesses as seen in the Delphi survey*

Sections 2 and 3 discussed Japan's position in the nanotech and materials field as a whole by comparing it with other fields. This section addresses nine noteworthy science and technology areas in the nanotech and materials field in the Delphi survey and some of their technical issues in order to examine how experts in the field view Japan's R&D level.

Table 1 depicts assessment of the current R&D levels and rankings (5 levels) of the nine nanotech areas. Judging by area names and summaries, bottom-up technologies are listed in the upper part, with top-down technologies in the lower part. The numbers in the columns showing "vs. US" and "vs. EU" are obtained by indexing the added values of 5 levels into 10 ranks as in Figure 4. From these results, one can see that Japan is leading in top-down technology, but somewhat behind in bottom-up technology. Versus the US in particular, Japan's relative level is split in half by the equal level of 5.0.

However, there is a mixture of bottom-up and top-down technologies within some areas*5, although the percentages vary. Accordingly, this article addresses the Delphi topics for "Matter and materials origination, synthesis technology, and process technology," which is located in the middle range, displaying the evaluation results in Table 2. All the Delphi topics are assessed as technologies that are yet to be realized at present and should be or probably will be realized in the future. As in Table 1, in Table 2 the bottom-up oriented topics are in the upper part, with the top-down oriented topics in the lower part. In the Delphi survey, respondents selected for each of these Delphi topics the leading country or region from Japan, the US, EU, Asia (excluding Japan), and Other. Table 2 shows the countries or regions with the most votes. As in Table 1, Japan leads in top-down technologies, but is behind the US in bottom-up technologies, with one exception (nanotube manufacturing technology).

Although this analysis addresses topics in the area located in the middle of Table 1, topics in the remaining areas showed similar tendencies. For example, in areas with strong bottom-up elements, such as "nanomaterials modeling simulation" and "nanobiology," the US was overwhelmingly the leader rather than Japan. On the other hand, in areas with strong top-down

**Table 2** : Delphi survey results on the R&D levels of Delphi topics included in the area, "Matter and materials origination, synthesis technology, and process technology"

| | Technology topics included in the area "Matter and materials origination, synthesis technology, and process technology"*1 | Leading country*2 |
|---|---|---|
| Bottom-up | Technology to freely apply organic, inorganic, and metal materials at the nano level | US |
| | Methods for protein synthesis with optional structures through in-vitro sequence control that does not use mRNA or tRNA | US |
| | Manufacturing technology for nanotubes structured according to design | Japan |
| | Technology to freely control the structure and characteristics of surfaces and interfaces at the atomic level | US |
| | Technology to directly synthesize plastic from carbon dioxide gas and water, using light as an energy source | US |
| | Organic macromolecules with luminous surfaces for lighting | Japan |
| | Manufacturing technology using nano structure control for ultra-plastic ceramics | Japan |
| Top-down | Technology that uses gas phase coating to manufacture to manufacture tools harder than diamond | Japan |

*1: Of the 11 topics in this area, the 8 showing clearly significant differences (R1 of at least 10%) in the response results are listed.
*2: Leading country is selected from Japan, US, EU, Asia (excluding Japan), and Other.

Prepared by the STFC based on Reference[6]

elements, more responses cited Japan as the leader.

With the challenges of nanotech research expected to shift towards bottom-up technology in the future, there is concern that Japan will be weakened in science and technology competitiveness in this field versus the US. In other words, Japan, which has developed some strength in today's nanotech field centering on top-down technologies, may gradually lose competitiveness as the stages of competition shift towards bottom-up technologies and nanosystem materials development.

## 4-2 Characteristics of nanotech venture businesses

Recently, venture businesses assume increasingly important roles in the creation of innovation based on frontier science and technology such as nanotech, ICT, and biotechnology*6. Accordingly, Tables 3(1) and 3(2) show US and Japanese nanotech venture businesses*7 listed in the "Nanotech Business Directory" compiled by Nomura Research Institute, Ltd.[12]. In both charts, US venture businesses are listed in the left column, with Japanese in the right, and the core technologies of the businesses between them in the middle. The list is arranged subjectively, with differences in technological approaches shown on the vertical axis. They are judged as top-down or bottom-up oriented in accordance with the standards used in the previous section. It is readily apparent that more US ventures are successful in commercializing bottom-up technology stages. On the other hand, there are many Japanese ventures in top-down technology stages that are extensions of conventional technologies.

From an industry-wide perspective, at present there are few major differences among them. In the future, however, as the areas of nanotech competition shift from top-down technologies to bottom-up technologies and nano-systematization, there is concern that these differences in venture businesses will greatly affect Japan-US nanotech competitiveness.

## 4-3 Comparison of the characteristics of top-down and bottom-up technologies, and the relative decline of Japanese competitiveness

Table 4 compares the characteristics of top-down and bottom-up technologies. Top-down technologies aim to resolve technical problems in current technologies, shifting the focus from one specific problem to another. On the other hand, because bottom-up technologies involve high technological uncertainty, the cost to search for their scientific and technical seeds can be enormous. If, however, nanotech advances as shown in Figure 5 and nano-systematization technology becomes the core of R&D, there may be little competition in the nanotech field because of the highly sophisticated nature of technology. Table 4 also analyzes both kinds of technology by R&D strategies and the existence of markets, as well as typical technologies.

Figure 6 follows the premises of Figure 5 and Table 4 in presenting a conceptual representation

**Table 3(1)** : Comparison of Japanese and US nanotech venture businesses

Bottom-up technologies

| US nanotech ventures | Core technologies | Japanese nanotech ventures |
|---|---|---|
| Nanocrystals Technology<br>NANOSYS, INC.<br>ZIA LASER, INC. | Quantum dots | |
| CALIFORNIA MOLECULAR ELECTRONICS CO.<br>NANOLAYERS | Nano molecular devices | |
| NANOLOGIC, INC. | New types of computer | |
| NANOPLEX TECHNOLOGIES, INC.<br>NANOSPECTRA BIOSCIENCE, INC.<br>NANOSPHERE, INC.<br>QUANTUM DOT CORPORATION | Bio applications of nanoparticles | |
| NANOCHIP, INC.<br>NANOMAGNETICS LTD.<br>ZETTACORE, INC. | Ultrahigh-density memory | Optoware Co., Ltd. |
| Biophan Technologies, Inc.<br>Broptics Communications Corp.<br>Konarka Technologies, Inc.<br>Quantum Polymer Technologies | New functional materials<br>(Shield materials,<br>polymer solar cells,<br>conducting plastic nano-wires) | Nac Corporation |
| Molecular Nanosystems<br>NANOMIX<br>Zyvex Corporation | CNT (carbon nanotube)<br>devices | Proton C60 Power Corporation<br>Japan Gain the Summit Co., Ltd. |
| AVIVA BIOSCIENCES<br>BIOMICRO SYSTEMS, INC. | μ-TAS<br>(microintegration analysis systems) | Institute of Microchemical<br>Technology Co., Ltd.<br>Fluidware Technologies, Inc. |
| FLUIDIGM CORPORATION<br>Micronics, Inc.<br>NanoSpire<br>NANOSTREAM | | |
| iMEDD, INC. | Nanomembranes | Bio Nanotech Research Institute |
| ARRYX, INC. | fs-lasers<br>Laser manipulation, etc. | Alnair Laboratories Corporation<br>Cyber Laser Inc. |
| BIOFORCE NANOSCIENCES, INC.<br>Cytoplex Biosciences, Inc.<br>Excellin Life Sciences, Inc.<br>GENICON SCIENCES CORPORATION<br>IMAGO SCIENTIFIC INSTRUMENTS<br>CORPORATION<br>Intergrated Nano-Technologies<br>Nano0sensors<br>PICOCAL<br>SPINELIX<br>Triton BioSystems, Inc. | Inomu assay<br>Probing<br>Biosensors<br>Biochips | Research Institute of Biomolecule<br>Metrology Co., Ltd. |
| Quantum Precision Instruments Pty Ltd. | Ultra-compact sensors, MEMS<br>sensors, etc. | Levex Corporation<br>Photonic Science Technology,<br>Inc. |
| Alinis BioSCiences, Inc.<br>C SIXTY, INC.<br>INSERT THERAPEUTICS, INC.<br>NANOMED PHARMACEUTICALS, INC. | DDS (drug delivery systems) | LTT Bio-Pharma Co., Ltd.<br>Interprotein Corp.<br>NanoCarrier Co., Ltd. |
| | Artificial skin and retinas | NIDEK |
| NeoPhotonics<br>OPTIVA, INC.<br>SiWAVE, INC. | Optical IC | Photonics Lattice, Inc.<br>dept Corporation |
| NanoGram Devices<br>NANOPOWDER ENTERPRISES, INC.<br>Nano-Tex, LLC.<br>NTERA LTD. | Physical applications of<br>nanoparticles | Clean Venture 21 |

**Table 3(2)** : Comparison of Japanese and US nanotech venture businesses (continued)

| | U.S. nanotech venture business | Core technologies | Japanese nanotech venture business |
|---|---|---|---|
| Top-down technologies ↓ | NANOMUSCLE<br>nPOINT, INC. | Nanoactuators | Nano Control Co., Ltd.<br>Eamex Corporation<br>HEPHAIST SEIKO Co., Ltd. |
| | CARBON NANOTECHNOLOGIES, INC.<br>Eikos, Inc. | CNT manufacturing | Carbon Nanotech Research Institute<br>NanoCarbon Research Institute Co., Ltd.<br>Frontier Carbon Corporation |
| | ADVANCED DIAMOND TECHNOLOGIES<br>ATOMIC-SCALE DESIGN, INC.<br>CHEMAT TECHNOLOGY, INC.<br>INMAT LLC. | Nanocoating | SNT (Shiratori NanoTechnology) Co.<br>T&K inc. |
| | NANOINK, INC.<br>NANONEX CORPORATION<br>NANOOPTO CORPORATION | Nanoimprinting | MEMS CORE Co., Ltd.<br>Itrix Corporation<br>Device Nanotech Research Institute<br>Nanodevice System Research Institute |
| | ALTAIR NANOTECHNOLOGIES, INC.<br>CIMA NANOTECH (Nano Powders Industries)<br>Five Star Technologies, Inc.<br>Hi-Q Materials, Inc.<br>MATERIALS MODIFICATIONS, INC.<br>Nano Interface Technologies, Inc.<br>Nano Gram<br>NanoHorizons, Inc.<br>Nanomaterials Discovery Corp.<br>Nanomys, Inc.<br>NANOTECHNOLOGIES, INC.<br>NANOVA, LLC.<br>NANOVENTIONS, INC. | Nanoparticles and nanostructure manufacturing technology, etc. | Nihon Nanotech Co., Ltd.<br>Millennium Gate Technology Co., Ltd. |
| | Nanometrology LLC. | Nanomeasurement technology | Tsukuba Nanotechnology Co. Ltd.<br>Technos International, Inc.<br>Tokyo Instruments, Inc.<br>Nanotex Corporation<br>Nanophoton Corp.<br>JASCO Corporation<br>Wyckoff Co., Ltd. |
| | | Nanofabrication, precision machinery fabrication technology, etc. | Adept Japan Co., Ltd.<br>X-ray Precision, Inc.<br>Elionix Co., Ltd.<br>Cluster Technology Co., Ltd.<br>Crestec Corporation<br>Nano Corporation |
| | | Crystal growth technology | Nitride Semiconductors Co., Ltd.<br>Nanoteco Corporation<br>SiXON Ltd.<br>Oxide Corporation |
| | Sherman & Associates, Inc. | Vacuum equipment/ Microfabrication processing equipment, etc. | R-DEC Co., Ltd.<br>ADTEC Plasma Technology Co., Ltd.<br>Optorun Co., Ltd.<br>Katagiri Engineering Co., Ltd.<br>Science Technology Co., Ltd.<br>Nanotec Corporation<br>Youtec Ltd.<br>Litho Tech Japan Co., Ltd. |

Prepared by the STFC based on Reference[12]

of changes in nanotech competition stages. There is concern that Japan, currently strong in top-down technologies, might gradually lose global competitiveness as the competition stages for technologies change.

**Table 4** : Comparison of characteristics of top-down and bottom-up technologies

| | Top-down technologies | Bottom-up technologies |
|---|---|---|
| R&D directions and technical characteristics | Stepwise progression towards physical limits by miniaturization<br>Scaling down (from microlevel)<br>Analytical | Shifting to nanosystems at molecular level<br>Scaling up (from nanolevel)<br>Interpretive: Large technological discontinuities |
| R&D strategies | Roadmap-type strategies<br>Continuous | Non-roadmap type strategies and creation of new industries<br>Probabilistic |
| R&D targets and markets | Clear (to some extent) | Uncertain and exploratory |
| Interrelationships | Problem proposing (for bottom-up technology) | Solution proposing (for top-down technology) |
| Typical technologies | • Semiconductor miniaturization technology<br>• Nano-compound materials, etc. | • Molecular devices<br>• Self-organization technology, etc. |
| Japan's competitiveness (vs. US) | High | Low |

## 5 Innovation systems for nanotech commercialization

### *5-1 Construction and promotion of basic research supporting nano-systematization (towards nanotech research)*

In order to develop bottom-up technologies and ultimately achieve nano-systematization, R&D on the scientific foundation that supports it is indispensable. Section 4-1 introduced some bottom-up technologies based on the results of the Delphi survey. There is concern that Japan, currently strong in top-down technologies, might lose global competitiveness in the future. In order to target improved global competitiveness in the area of nano-systematization, nanotech researchers must carry out basic R&D with a keen awareness of R&D in areas of high uncertainty.

However, it may be difficult for researchers involved in research on nano-systematization technologies to produce a large amount of articles and other forms of results[*8]. Unlike top-down technologies that enable relatively easy data collection, bottom-up technologies and future nano-systematization technologies deal with an almost infinite number of uncertainties, making it extremely difficult to carry out reproducible experiments or to verify hypotheses. In the first place, the kind of state-of-the-art measurement and analysis that can be considered nanoscience must be conducted in environments with uniform measurement conditions and parameters, so it tends to end up being only analysis or measurement. In this sense, one may say that few basic research methods have been established for bottom-up or nano-systematization technologies. This article asserts that true nanotech competitiveness in the future will be demonstrated in the areas of the molecular fabrication and systematization of nanostructures, where an uncounted number of elements are involved. From this point of view, Japan must structure and enhance its new nanoscience research method.

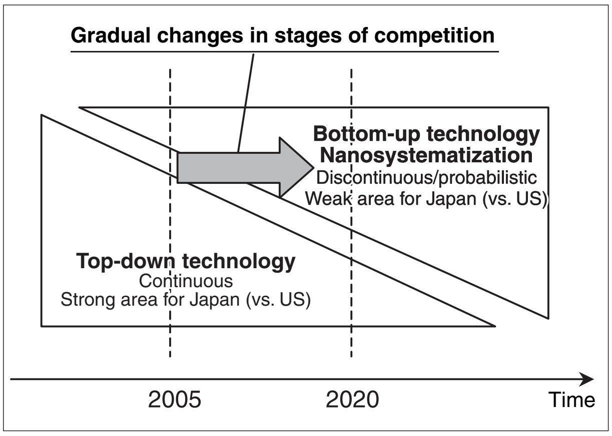


**Figure 6** : Comparison of characteristics of top-down and bottom-up technologies

### *5-2 Construction of the nanotech venture creation system and funding functions (towards industry)*

In order to create nanotech ventures, the following social and economic characteristics of nanotech must be considered.

- Inability to apply traditional categories, such as academic fields or industrial classifications, because of many transdiciplinary or interdisciplinary elements involved in R&D

- High expectations - the potential to renovate markets or even economic society
- Extremely large ripple effects
- Geometric increase of investment from discovery/invention to commercialization of technology
- A need for continuous and incremental investment because of the difficulty of accurately determining the right investment size in advance, and because of the significance of cumulative effects
- A need for an innovation system as a supplementary system to diversify risks associated with sharply rising investment

As these characteristics show, investment in nanotech, especially its bottom-up technologies, involve high technological uncertainty, and therefore its effects are only probabilistic. Unfortunately, Japanese mechanisms for investment in state-of-the-art R&D are not as complete as those of the US. This is particularly true for investment in venture businesses. The current mainstream financing system in Japan is that a single company or a joint investment entity formed by banks, securities companies, and major manufacturers support a venture company from startup to technology development to commercialization. However, the investment amount for new businesses is smaller than that of the US, and the venture capital industry, which plays an important role in investment activities and the R&D processes, is still immature in Japan. In other words, an innovation system that can accommodate the above characteristics of nanotech, especially those of bottom-up technologies, has not established yet. The current situation in Japan is that nanotech venture businesses are reliant largely on public support, from R&D to commercialization*9. However, considering that bottom-up technologies may require more than 15 years of continuous investment to reach commercialization, public support programs alone cannot provide sufficient funding. A solution to this is a system in which a different funding source is used in every stage from startup through early, middle, and later stages. This would substantially reduce the risk to be born by each funding source and thereby restrict the total capital invested by each funding source.

### *5-3 Pioneering methods of creating new R&D management tools (towards management research)*

Technology roadmaps, which have developed around the typical top-down R&D field of semiconductors, have played a role in securing the rationality of advance investment by clarifying the direction of investment and even predicting socioeconomic ripple effects. However, because of the following characteristics of the nanotech field, especially its bottom-up technologies, traditional methods of setting R&D strategies are no longer effective enough[18].

- Compared with the other fields (especially semiconductors), this field is lacking in structured technologies and shared recognition of future markets[19]
- Because bottom-up technologies by nature are aggregate concepts from myriad technology seeds, searching for commercially useful technology seeds is a task encompassing a broad scope and requiring enormous costs
- Because technology has a strong tendency to develop through non-linear processes, the route from investment to result is uncertain
- The advanced level and complexity of the technologies make it difficult not only to judge investment rationality in advance but also to measure the economic effects of the investment afterwards
- As technology develops, investment amounts may grow enormously and become difficult to recover
- For these reasons, investment is high risk/ high return and is often underfunded

Because of these issues, study of methods for the creation of new R&D management tools is necessary. For example, the recent development of option theory is attracting attention. Since nanotech, especially its bottom-up technology, encompasses a broad range of technologies, there is a potentially ironic situation where a roadmap created through an extensive selection and concentration process is more likely to become useless depending on future trends in technology development. Maintaining the flexibility*10 of a technology roadmap towards pre- and post-roadmap events is therefore a key determinant of the future destiny of the nanotech field[20-21]. Incorporating a broad range of technology could be a great risk in conventional roadmapping methods, but the abundance of technology options available there could provide a means to hedge the risk of increased uncertainty in the future. The essence of a technology roadmap is to "visualize" options. In option theory, it is possible to see the expectations and uncertainties of advance options as ex post facto value. Conventionally, uncertainty has been something to be avoided as much as possible, but option theory shows that uncertainty also has value. The development of option theory may be able to theoretically establish results with latent potential.

Although option theory is used as an example here, it is obviously not the only possibility. At the research level, a technology roadmapping method that uses text mining is also being studied[22]. From the perspective of securing the diversity of options, Delphi surveys are attracting renewed attention because of their capacity to include many technological issues and information related to them, such as the levels of given technologies. Management researchers must therefore study new types of methods based on such policies and industry requirements. The nanotech field may soon experience the difficulty of managing state-of-the-art R&D. Establishment of new strategy creation methods in this field would be of great significance to other frontier R&D fields.

**Notes**

1 The Nanotechnology Network Center's "Nanotechnology literature trend survey"[3] performs keyword-based searches of nanotech-related literature. According to that report, Japan ranks third in nanotech-related articles, behind the US and China.

2 The 10 areas are nanomaterials modeling simulation; nano measurement and analysis technology; nano processing, molding, and manufacturing technology; matter and materials origination, synthesis technology, and process technology; new materials from nanolevel structure control; nano devices and sensors; NEMS technology; environment and energy materials; nanobiology; and nanoscience for a safe and secure society.

3 The term "nanosystem" is used in the US as part of the names of academic society subgroups as well as research centers of universities and research institutes. Nanosystem research is actively progressing in these research centers, a representative example of which is UCLA's California NanoSystems Institute (founded in 2000)[8]. On the other hand, the term is rarely used in Japan, but in its strategic program called "Nanosynthesis: creative monodzukuri"[9] project, the Japan Science and Technology Agency broadly analyzes research and development of "nanodevices and nanosystems" and strongly emphasizes their importance.

4 Generally, in fields such as business administration and management of technology (MOT), management that emphasizes R&D strategies or directions decided by government or organization leaders is referred to as top-down strategies or approaches, while management that emphasizes the ideas and interests of frontline researchers and activities at the individual level is referred to as bottom-up strategies or approaches. Top-down and bottom-up technologies in the nanotech field are different from this. The terms are simply used to classify the broad field of nanotech by technical approach[10-11].

5 This article addresses top-down and bottom-up technologies by a relative definition. For example, although it refers to nanomaterials simulation technology as a representative bottom-up technology, obviously both top-down and bottom-up elements constitute this technology. An example of its top-down element is the common practice of fitting the data obtained by experiments through modeling in order to elucidate physical structures unobtainable through experimentation alone. An example of its bottom-up element can be seen in attempts

to perform simulations of every behavior of molecules in order to integrate their behaviors and create nanosystems so that completely new nanofunctional materials can be designed.

6 Research to date on management of technology (MOT) has found that large companies generally tend to make negative decisions on R&D in niche technologies that involve a high degree of uncertainty regarding commercialization and that are unlikely to create a market of a reasonable scale, in fear of declines in their R&D efficiency. (See references 13 and 14, for example.) On the other hand, R&D with this kind of high uncertainty is essential for achieving disruptive innovation. From this perspective, R&D ventures that hedge risk by diversifying funding sources and maintain small-scale operating and development structures are garnering attention. (See Reference 15, for example.)

7 Reference 12 derives 77 US and 59 Japanese firms from the following materials.
US: Nanotech Venture Fair 2002 (San Diego)
Nanotech Planet Spring 2002 (San Jose)
Nanotech Venture Fair 2003 (Coronado)
Japan: Derived from "Leading cases of nanotech ventures" (management information search, summer 2002), "Japanese nanotech ventures (summary ed.)," (Nikkei Nanotechnology, August 25, 2003), "Japanese nanotech ventures (individual company ed.)," (Nikkei Nanotechnology, September 8, 2003), "FY 2004 ultraminiaturization technical development industry excavation strategy survey: Field survey of nanotech venture companies" (Ministry of Economy Trade and Industry commissioned survey), etc., and Nikkei Shimbun
Many other ventures have started since 2005; they are not included.

8 In NISTEP's research paper analysis using citation relationships[16], the bottom-up technology research area "Building of nano-structures from microstructure with microparticles and polymers" is listed as one of 133 research areas. Japan's share of the most-cited papers in this research area was about 3.7 percent, low compared to other nanotech-related areas.

9 Nomura Research Institute and many METI-commissioned surveys carry out detailed analyses of nanotech ventures. According to one of these, Reference 17, about 79 percent of nanotech venture businesses have received public R&D subsidies. Moreover, their applications for subsidies have been accepted at an astonishing rate of 88 percent. Nevertheless, about 55 percent of nanotech ventures operate at a loss.

10 For example, current technology roadmaps are updated to meet changes that were unpredictable at the time of formulation, through annual revisions after the fact. In the future, however, management tools that can even visualize technologies outside the roadmap (off-road technologies) as options need to be developed.

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4

# Research and Development Trends in Energy Crops and Biofuel Conversion Technologies

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## 1 Introduction

To solve global warming problems and ensure sustainable development of the economy, it is necessary to increase the use of renewable biomass resources. The magazine "Science & Technology Trends", published articles on the possibilities of bio-energy and the trends in the technological developments, spread and introduction of policies adopted in many countries[1,2]. In recent years, there have been active movements to accelerate the spread of liquid biofuels as alternative to gasoline and diesel fuel in a large number of countries, for enhancing their energy security, managing high crude oil prices and overcoming gloval warming problems.

Recently, international crude oil prices have risen rapidly and temporarily exceeded US$80/barrel. The increases in prices were due to various factors such as the risk of political instability, the rapid development of BRICs' economy, and the disruption of oil supply infrastructures by natural disasters. Considering that the world production of oil will inevitably reach its peak in the medium or long term, it is most likely that the trend for oil prices to increase will continue. In such a tough situation, most of the transportations such as automobiles, aircrafts and ships continue to depend on crude oil by the reason of no alternatives for economically providing energy.

In many countries, it is generally recognized that it is urgently necessary to reduce dependence on oil for transport energy. Thus, much attention is concentrated on research on energy crops to provide biomass as an energy resource and on low-cost biofuel conversion technologies indispensable for the widespread adoption of bio-energy.

In Japan, where self-sufficiency in food is 40% at most, discussions on biomass use have been limited to the utilization of domestically unused wastes as energy resources, given that any increase in producing biomass as an energy resource would be in competition with food production. Therefore, sufficient study has not been made of the requirements, such as the availability of biomass resources, costs and quality stability, for the large-scale introduction of biofuels as alternatives to crude oil. Japan has started somewhat late in its movement toward the commercialization of biofuels, compared with other countries where such movements are increasingly active.

This article reviews the potential of biofuels as alternatives to crude oil in the world and in Japan, and summarizes the research and development trends for energy crops and biofuel conversion technologies essential to the development of biofuels. In addition, it describes problems encountered in the efforts made in Japan to develop biofuel technologies, and discusses the issues on which future research should focus.

## 2 Present situation and potential of biofuels as transport energy resources

### 2-1 Social background to biofuel production

Carbon contained in biomass is derived from $CO_2$ fixed from the atmosphere while plants are growing. Biomass could be considered to be a carbon-neutral energy resource if the release of $CO_2$ into the atmosphere as a result of the combustion of biomass is counterbalanced by the fixing of $CO_2$ as part of the solar energy driven carbon cycle (Figure 1). Then, if the biomass is used as a fuel alternative to fossil resources-based fuels such as crude oil, it is possible to reduce the emissions of greenhouse gases during the life cycle of the biomass, and provide a very effective means to take measures against global warming[4].

Biomass-based liquid fuels, what are called biofuels, are the most likely of the potential renewable energy resources for transport energy to succeed, because it is relatively easy to introduce biofuels, independently or as a mixture with a fossil-based liquid fuel, into existing internal combustion engine and distribution infrastructures. In Japan, annual $CO_2$ emissions are now 1.36 billion tons-$CO_2$, of which the emissions from motor vehicles accounts for about 20%, or 2.3 million tons-$CO_2$[5]. If total $CO_2$ emissions in Japan were reduced by 20% by replacing all fuels for motor vehicles with carbon-neutral biofuels, emissions would decrease to 1.13 billion tons-$CO_2$, which is lower than the reduction target of 1.23 billion tons-$CO_2$ (6% lower than the level in 1990).

Amongst biomass-related technologies, there are various combinations of raw materials, conversion technologies and use patterns (Figure 2). Liquid biofuels are suitable for use as transport energy because of high energy density. At present, the use of biofuels is mostly confined to agricultural countries which have abundance of low cost energy crops (Figure 3). However, in Japan, which has scanty energy crop resources,

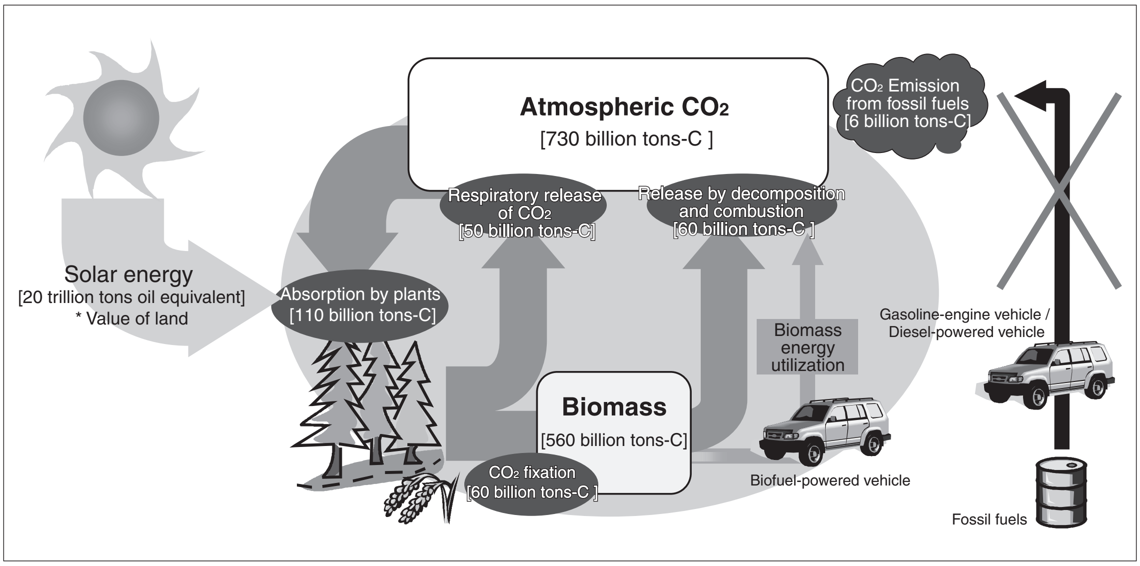


**Figure 1** : Atmospheric carbon cycle and carbon-neutral biomass energy

Prepared by the STFC based on Reference[3]

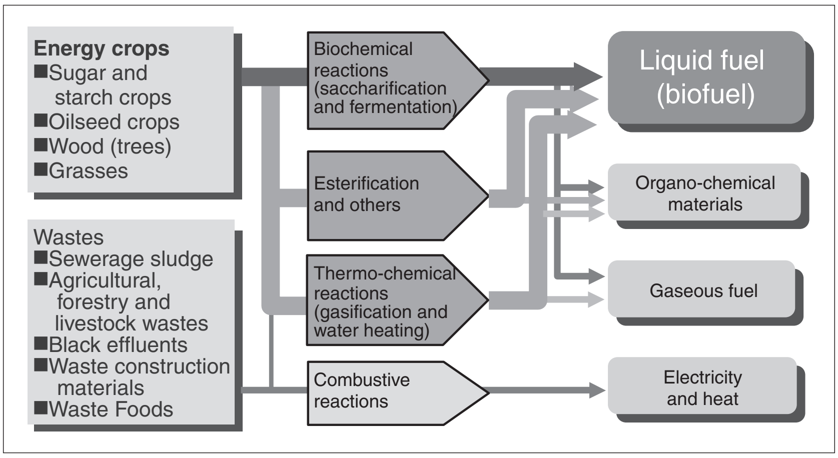


**Figure 2** : Raw materials and use for biomass-related technologies

Prepared by the STFC based on Reference[6]

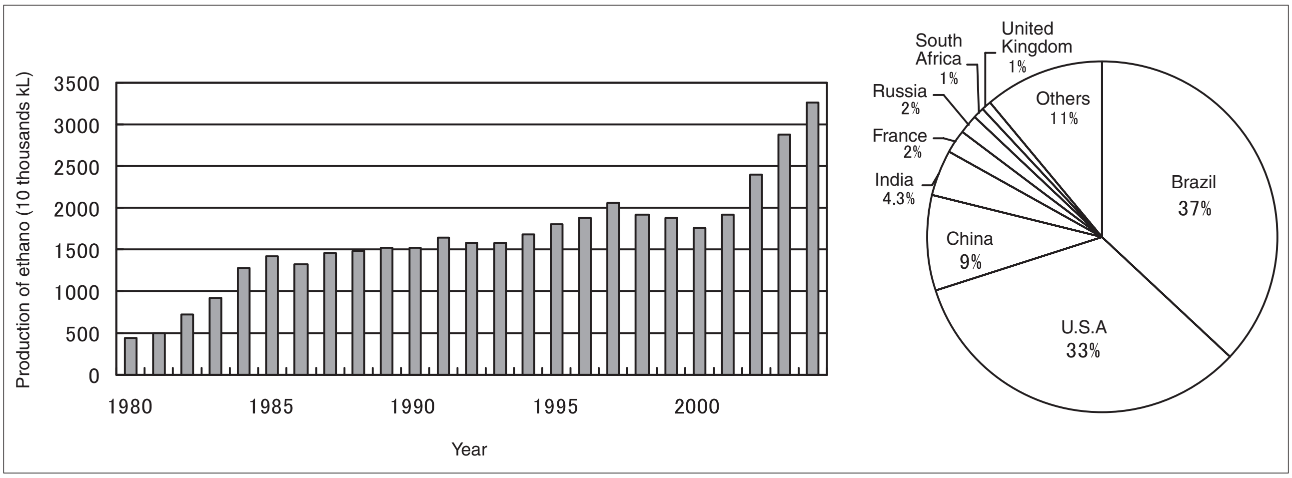


**Figure 3** : World trend of bio-ehtanol production and each country's share in 2004

Prepared by the STFC based on Reference[6]

biofuels are produced mainly from waste-based resources such as waste construction materials and food oil, and the production of biofuels is extremely limited in regional and quantitative terms.

## 2-2 Global trends of biofuel promotion policy

There are many overseas countries where the spread and introduction of biofuels is actively promoted. In these countries, not only compulsory quantitative targets for the introduction of biofuels in the medium- and long-term established, but other measures for accelerating the spread of biofuels, including changes in the taxation system, are being established (Table 1). In the U.S.A. and the EU, importance is attached to promoting agriculture and forestry, both to ensure energy security and to take measures against global warming. In China, in addition to these challenges, greater importance is attached to coping with the increasing energy consumption by the growing economy. In Brazil and ASEAN countries, priority has primarily been given to industrial development and the eradication of poverty mainly by increasing exports to foreign countries. As a consequence, these countries are inevitably required to reduce the resultant adverse influences on the environment such as excessive deforestation of tropical rain forests.

Thus, the policies leading to the spread of biofuels had different origins in different countries. However, the policy in each country clearly considers biofuels to be alternatives to transport energy in the medium- and long-term. It is common to all countries that they have produced crops for energy (energy crops) with economical feasibility, have set quantitative targets for the introduction of biofuels, including compulsory targets, and established a variety of systems supporting the production and spread of biofuels.

In Japan as well, the "Kyoto Protocol Target Achievement Plan"[7], adopted by the Cabinet Council in April 2005, set a quantitative target of 500 thousand kl-crude oil equivalent for biofuels used in the transport sector. The "Biomass Nippon Strategy"[8], decided by Cabinet Council in March 2006, established the significance and objectives for the introduction biofuels, and has accelerated the implementation of the measures taken to promote the utilization of biofuels. In November 2006, Mr. Abe, Former Prime Minister, ordered an increase in the domestic production of biofuels, from the viewpoints of protecting the global environment and supporting regional development and agriculture. To comply with the Prime Minister's order, an implementation plan was developed by the "Biomass Japan Comprehensive Strategy Promotion Council" in which the Ministries and Agencies concerned, including the Ministry of Agriculture, Forestry and Fisheries, participated[9]. The industries concerned in Japan also provided a model for the large-scale production of low cost biofuels as well as their proposals on the roadmap for

**Table 1** : Biofuels introduction policies by country

| Region | Country | Mixing ratio | Materials | Vehicle provisions | Target / obligation to introduce biofuels | Actions to support the spread of biofuels |
|---|---|---|---|---|---|---|
| North America | U.S.A | E10/E85 | Corn | E10 suitable vehicles marketed<br>FFVs marketed | Obligatory quantitative targets for renewable fuels introduced were set under the Energy Policy Act in 2005<br>2006: 4.0 billion gallons (about 15 million kl, equivalent to 2.8% of the total gasoline distribution)<br>2012: 7.5 billion gallons (about 2.8 millions kl)<br>Quantitative targets for the introduction of renewable and alternative fuels were set in the US president's State of the Union address in 2007<br>2017: 35 billion gallons (about 1.3 billion kl) | Fuel tax credit action<br>Support and loan project for fuel manufacturers |
| | | B2~5/B20/B100 | Soybean and waste food oil | B10 and B100 suitable vehicles marketed | | |
| | Canada | E5~10/E85 | Corn, wheat and barley | E10 suitable vehicles marketed<br>FFVs marketed | A quantitative target for the introduction of ethanol was set in the Ethanol Utilization Increase Program in 2003.<br>2010: 35% of the gasoline consumption will be replaced with E10. | Fuel tax reduction<br>Financial support for the construction of fuel manufacturing facilities |
| Middle & South Americas | Brazil | E20/E25/E100 | Sugar cane | E25 suitable vehicles marketed<br>FFVs marketed | A compulsory mixing ratio of 20 to 25% ethanol to gasoline was imposed. | Actions for reducing the federal industrial tax and local tax on ethanol available vehicles |
| | | B2 | Soybean | B25 and B100 suitable vehicles marketed | A compulsory mixing ratio of bio-diesel to light oil was imposed (2% by 2008 and 5% by 2013). | Fuel tax reduction |
| Europe | EU | — | — | — | Quantitative targets for Biofuels introduction were set under the EU Biofuel Directive in 2003 and the EU Renewable Energy Road Map in 2007.<br>2005: A ratio of 2% of biofuel to transport fuel<br>2010: 5.75% biofuel to transport fuel (equivalent to 21 million kl)<br>2020: At least 10% biofuel to transport fuel<br>The obligatory introduction of biofuel is under consideration under the Biomass Action Plan of 2005 and the Biofuel Strategy of 2006 | Support for the cultivation of energy crops |
| | Germany | ETBE | Rye and wheat | | A quantitative target for biofuel introduction was set under the EU Biofuel Directive in 2003<br>2005: A ratio of 2% of biofuel to transport fuel | Fuel tax reduction<br>Support for the cultivation of energy crops |
| | | B5/B100 | Rapeseed | B100 suitable vehicles marketed | | |
| | France | ETBE6~7 | Sugar beat and wheat | | A quantitative target for biofuel introduction was set under the EU Biofuel Directive in 2003<br>2005: A ratio of 3% biofuel to transport fuel | Fuel tax reduction<br>Support for the cultivation of energy crops |
| | | B5/B30 | Rapeseed | B30 suitable vehicles marketed | | |
| | United Kingdom | E5 | Corn | | Quantitative targets for biofuel introduction were set under the EU Biofuel Directive in 2003<br>2005: A ratio of 0.3% of biofuel to transport fuel<br>2010: A ratio of 5% of biofuel to transport fuel (*The compulsory introduction system will start to be implemented in 2008) | Fuel tax reduction<br>Support for the cultivation of energy crops |
| | Sweden | E5/E85 | Wheat | FFVs marketed | A quantitative targets for biofuel introduction were set under the EU Biofuel Directive in 2003<br>2005: A ratio of 3% of biofuel to transport fuel | Fuel tax reduction<br>Support for the cultivation of energy crops |
| | Spain | ETBE3~4<br>ETBE6~7 | Wheat and barley | | A quantitative target for biofuel introduction was set under the EU Biofuel Directive in 2003<br>2005: A ratio of 2% of biofuel to transport fuel | Fuel tax reduction<br>Tax exemptions for fuel manufacturers<br>Support for the cultivation of energy crops |
| | Italy | B5/B30 | Rapeseed and sunflower | B30 suitable vehicles marketed | A quantitative target for biofuel introduction was set under the EU Biofuel Directive in 2003<br>2005: A ratio of 2% of biofuel to transport fuel | Fuel tax reduction<br>Support for the cultivation of energy crops |
| Asia | India | E5 | Sugar cane | | The introduction of E5 over the entire country began in 2003. The final goal is to spread E10 all over the country. | Fuel tax reduction |
| | | B5 | Jatropha | | 2005 to 2007: Demonstration testing<br>2007 to 2010: The supply area will be expanded, and B5 production and distribution facilities will be established.<br>2011 to2012: The introduction of B5 over the entire country will begin. | |
| | China | E10 | Corn and wheat | | A quantitative target for biofuel introduction was set under the Ethanol-Gasoline Introduction Plan in 2004.<br>2005: E10 was adopted in 4 provinces. | Consumption tax exemption for ethanol producers<br>Support for the cultivation of energy crops<br>Ethanol indirect tax refund action |
| | Thailand | E10 | Cassava | | A quantitative target for biofuel introduction has been set<br>2011: The introduction of E10 will be completed. . | Excise tax exemption for ethanol<br>Support for E10 producers |
| | | B2 | Palm | | Quantitative targets for biofuel introduction have been set.<br>2006: B2 introduction was completed.<br>2011: B3 introduction will be completed. | |
| | Philippines | E5 | Sugar cane | E10 suitable vehicles marketed since 1995 | A quantitative target for biofuel introduction was set under the National Ethanol Fuel Program in 2005.<br>2010: The introduction of E10 will be completed. | |
| | | B1 | Coconut | | The compulsory use of B1 will be imposed on Government vehicles | |
| | Malaysia | B2~5 | Palm | | A quantitative target for biofuel introduction was set under the National Biofuel Policy in 2005. | |
| | Indonesia | B5 | Palm | | A quantitative target for biofuel introduction was set under the National Energy Management Law.<br>2025: The use of BDF will be 4.7 millions kl. | |
| Oceania | Australia | E10 | Sugar cane | E10 suitable vehicles marketed | A quantitative target for biofuel introduction will be set under the Federal Government's Targets.<br>2010: 350 thousands kl | Support for ethanol producers |

Abbreviations: E is ethanol, B is bio-diesel, and ETBE is ethyl tertiary-butyl ether. The figures are mixing ratios by volume.

Prepared by the STFC based on Reference[6] technological development, on research and development organization, and on cooperation with the other Asian countries[10].

However, Japan, unlike some overseas countries, has not yet introduced any biofuel that could compete in terms of cost with conventional fossil fuels. Therefore, obligatory medium- and long-term targets for the introduction of biofuels and incentives for the widespread distribution and adoption of biofuels, including changes to the tax system, have not been established in Japan.

## *2-3 Potential for supplying biofuels in view of land use availability*

In contemplating introduction of biofuels as a full-scale alternative to conventional fossil fuels, it is necessary to take the potential competition over land between biofuels and food crops into consideration. It is predicted that the world population will reach a peak of about 9.2 billion around 2050[11]. The question is whether the world's agricultural lands will be able to supply the demands for both biofuel and food production at that time.

**Table 2** : Estimations of biofuel supply potential in 2050

(a) Case based on predictions by the United Nations

| Year | 1970 | 2000 | 2015 | 2030 | 2050 |
|---|---|---|---|---|---|
| World Population | 3.7 billion | 6.1 billion | 7.1 billion | 8.1 billion | 9.1 billion |
| Annual demand for cereals per capita | 0.33 t/capita | 0.34 t/capita | 0.33 t/capita | 0.33 t/capita | 0.33 t/capita |
| Warld's total annual demand for cereals | 850 million t | 2,040 million t | 2,320 million t | 2,680 million t | 3,010 million t |
| Annual yield per area | 1.3 t/ha | 2.9 t/ha | 3.3 t/ha | 3.3 t/ha | 3.3 t/ha |
| Necessary area for food producing | 650 million ha | 670 million ha | 700 million ha | 810 million ha | 910 million ha |
| Required increase in food producing area (over the area in 2000) | | | | | 240 million ha |
| Area available for energy production | | | | | 260 million ha |
| Annual production of ethanol (estimated) | | | | | 1,030 million kl |

(b) Case assuming increased demand for foods

| Year | 1970 | 2000 | 2015 | 2030 | 2050 |
|---|---|---|---|---|---|
| World Population | 3.7 billion | 6.1 billion | 7.1 billion | 8.1 billion | 9.1 billion |
| Demand for cereals per capita | 0.33 t/capita | 0.34 t/capita | 0.35 t/capita | 0.37 t/capita | 0.41 t/capita |
| World's total annuals demand for cereals | 850 million t | 2,040 million t | 2,500 million t | 3,010 million t | 3,760 million t |
| Yield per area | 1.3 t/ha | 2.9 t/ha | 3.3 t/ha | 3.3 t/ha | 3.3 t/ha |
| Necessary area for food producing | 650 million ha | 670 million ha | 760 million ha | 910 million ha | 1,140 million ha |
| Required increase in food producing area (over the area in 2000) | | | | | 470 million ha |
| Area available for energy production | | | | | 30 million ha |
| Annual production of ethanol (estimated) | | | | | 130 million kl |

(c) Case assuming increased yield/ha

| Year | 1970 | 2000 | 2015 | 2030 | 2050 |
|---|---|---|---|---|---|
| World Population | 3.7 billion | 6.1 billion | 7.1 billion | 8.1 billion | 9.1 billion |
| Demand for cereals per capita | 0.33 t/capita | 0.34 t/capita | 0.35 t/capita | 0.37 t/capita | 0.41 t/capita |
| World's total annuals demand for cereals | 850 million t | 2,040 million t | 2,500 million t | 3,010 million t | 3,760 million t |
| Yield per area | 1.3 t/ha | 2.9 t/ha | 3.3 t/ha | 3.6 t/ha | 3.9 t/ha |
| Necessary area for food producing | 650 million ha | 670 million ha | 760 million ha | 850 million ha | 960 million ha |
| Required increase in food producing area (over the area in 2000) | | | | | 290 million ha |
| Area available for energy production | | | | | 210 million ha |
| Annual production of ethanol (estimated) | | | | | 860 million kl |

Prepared by the STFC based on References[11-14]

The total area of land in the world is 145 billion ha, of which present agricultural land accounts for about 10 % of the total area[12]. A United Nations' FAO study reports that the total area of agricultural lands may be increased by about 1.8 billion ha[13]. However, 60% of the increase in agricultural land area will be forests and reserves, and 2/3 of them will be defective in terms of soil quality and topography. Therefore, if these areas are subtracted, it is estimated that the real increase in agricultural land area may be about 500 million ha.

Based on the United Nations' projections for the demand for cereals, it will be necessary to increase the food producing area by 240 million ha by 2050 when the world population is expected to reach its peak. Therefore, if the increase of 240 million ha in food producing area is subtracted from the total increase in agricultural land, the biofuels producing area is estimated at 260 million ha in 2050. The potential annual production of ethanol is estimated to be about 1.0 billion kl from this biofuels-producing area, assuming that the biomass productivity is 10dry-t/ha and the ethanol conversion efficiency is 0.4kl/dry-t (Table 2 (a)). The United Nations' projection assumes that future demands for cereals per capita will be almost the same as at present. However, the figure for future consumption seems to be rather low, considering the high economic growth in developing countries. The demand for cereals per capita has increased by 10% for the past 30 years. Supposing that this rate of increase will continue in the future, it is estimated that the potential annual production of ethanol would be decreased to 130 million kl (Table 2 (b)).

There are two possible approaches to ensuring the compatibility of the supply of foods with that of biofuels as described hereinafter. The first approach is to increase the yield of crops per hectare. The estimation above was based on the assumption that increases in the yield per hectare will level off after 2015. The yield of cereals per hectare increased at an annual rate of 3% in the 1960s, and it has increased at an annual rate of 1.5% since 1980s. It is predicted that the annual rate of increase will decrease to 1.1% by 2015[14]. Assuming that the yield per hectare increases at an annual rate of 1% after 2015, the potential annual production of ethanol in 2050 will be about 860 million kl (Table 2 (c)). It can be expected that this value will be readily attained if the productivity of crops is effectively improved by applying gene modification technologies to crops.

The second approach is by establishing innovative biofuel production technologies. In the U.S.A. and the EU, these technologies are generically known as the "second-generation" biofuel technologies, and research in this field has become increasingly active in recent years (Table 3). This is especially true of research in technologies for converting lignocellulose into ethanol at a low cost. Lignocellulose has not previously been widely used in biofuel production.

Lignocellulose is the main component of the plants cells in woods and caules (woody stems), and has the highest quantitative potential from the viewpoint of energy resources. It is composed mainly of cellulose, hemicellulose and lignin

**Table 3** : Second-generation biofuels

| | Type | Designation | Raw materials | Production technologies |
|---|---|---|---|---|
| Bio-ethanol | 1st generation | Conventional bio-ethanol | Sugar beet (sugar)<br>Cereals (starch) | Hydrolysis (saccharification) + fermentation |
| | 2nd generation | Cellulose-based bio-ethanol | Woods and herbage (Lignocellulose) | Pretreatment<br>Hydrolysis (saccharification) + fermentation |
| Bio-diesel | 1st generation | Fatty acid methyl ester (FAME) | Vegetable oil crops (e.g. rapeseed)<br>Waste food oil | Pressure extraction + ester exchange |
| | 2nd generation | BTL (Biomass to Liquid) | Woods and herbage (Lignocellulose) | Gasification + FT synthesis |
| | | BHD (Bio-Hydrofined Diesel) | Vegetable oil crops & animal fats | Hydrogenolysis |

Prepared by the STFC based on References[15-16]

(Figure 4).

However, while there are simple technologies for converting saccharides and starches in relatively wide use, there are no practical technologies for converting lignocellulose into ethanol[4]. If a suitable technology for converting lignocellulose into ethanol is developed, not only the starches and saccharides produced by cereals, but all parts of the plant including their stems and leaves, and also grasses and trees, will be effectively used as raw materials for producing ethanol. Thus, the amount of natural resources available for producing biofuels will be significantly increased. In the U.S.A. and Europe, therefore, much attention is concentrated on research on technologies for converting lignocellulose into ethanol.

### 2-4 Potential of biofuels in Japan

Here, the potential of biofuels in Japan is considered in terms of quantity and cost. The Biomass Japan Comprehensive Strategy Promotion Council estimates that it will be possible to produce 6 million kl/year of ethanol using domestic biomass resources in Japan (Table 4). To avoid competition with food production, it is supposed that non-food herbage-based biomass such as straw, and wood-based biomass such as the residual woods in forest lands will be used as raw materials for producing ethanol and that energy crops, such as rice and sorghum, will be grown on currently unused land.

In addition, the case for importing ethanol produced overseas as well as producing ethanol domestically using biomass resources

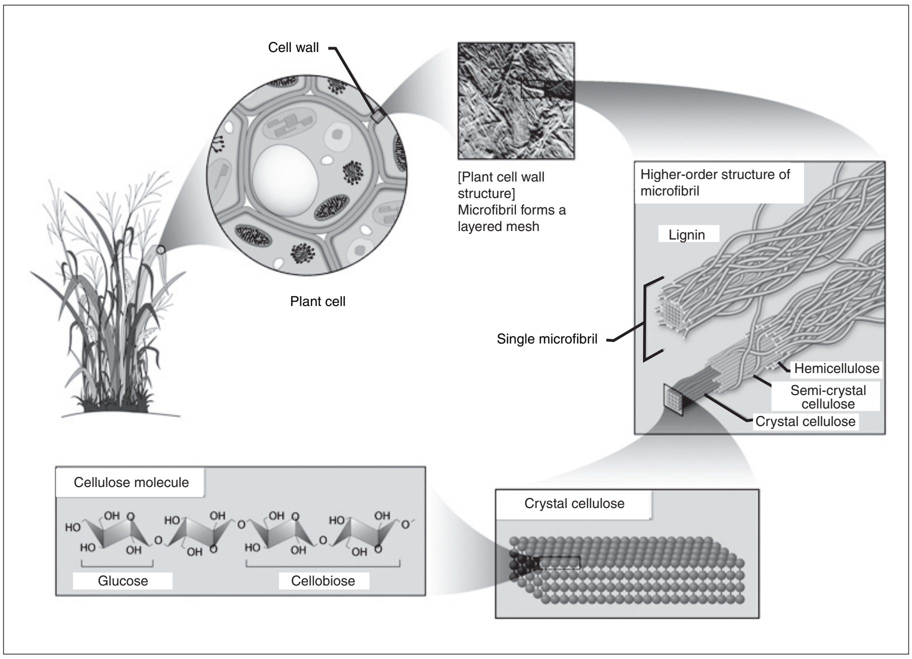


**Figure 4** : Plant fiber structure and lignocellulose

From Reference[16]

**Table 4** : Presumption of Japan's domestic biofuel supply under the Biomass Japan Comprehensive Strategy Promotion Council

| Raw materials | Predicted Production (FY2030) | |
|---|---|---|
| | Ethanol equivalent kl | Crude oil equivalent kl |
| 1. Sugar and starch (by-products in food production processes and sub-standard agricultural products) | 50 thousand kl | 30 thousand kl |
| 2. Herbage (such as rice straw and wheat straw) | 1,800 to 2,000 thousand kl | 1,100 to 1,200 thousand kl |
| 3. Energy crops (such as rice and sugar beet) | 2,000 to 2,200 thousand kl | 1,200 to 1,300 thousand kl |
| 4. Woods (such as waste construction materials and residual timber from forest lands) | 2,000 to 2,200 thousand kl | 1,200 to 1,300 thousand kl |
| 5. Bio-diesel fuels | 100 to 200 thousand kl | 60 to 120 thousand kl |
| Total | Approx. 6,000 thousand kl | Approx. 3,600 thousand kl |

From Reference[9]

is considered. A comparison of the two cases is shown in Figure 5. Bio-ethanol fuels which can compete with gasoline in price have already been distributed in the U.S.A. and Brazil, countries which are more advanced in terms of biofuels. In assessing the economics of importing bio-ethanol fuels from these countries, it is of course necessary to add to their prices the overhead costs of importing and distributing the fuel, customs charges on the imported fuels, and the investment costs for an ethanol distribution infrastructure. However, even when these costs are added to the prices for bio-ethanol fuels produced either in the U.S.A from corn or from sugar cane in Brazil, the lower limit of the estimated price range for ethanol fuels is lower than the gasoline prices in Japan, and prices are sufficiently competitive with the latter. In contrast, if ethanol is produced in Japan on the same scale as in the U.S.A. and Brazil using wheat as the cheapest edible cereal produced in Japan (at the price of 164 yen/kg), its price is estimated to equal or exceed 450 yen/l excluding gasoline tax. At these prices Japanese produced bio-ethanol would not be cost competitive with gasoline and the ethanol fuels produced overseas.

If ethanol is produced domestically in Japan, using domestic irregular rice not suitable for human consumption as a raw material (at the price of 20 yen/kg), its price without gasoline tax may be almost competitive with the prices for overseas produced ethanol and gasoline. The amount of irregular rice would have been limited in Japan and would not fill up the demand of bio-ethanol fuel. However, if non-edible rice, whose taste and appearance are not taken into account,

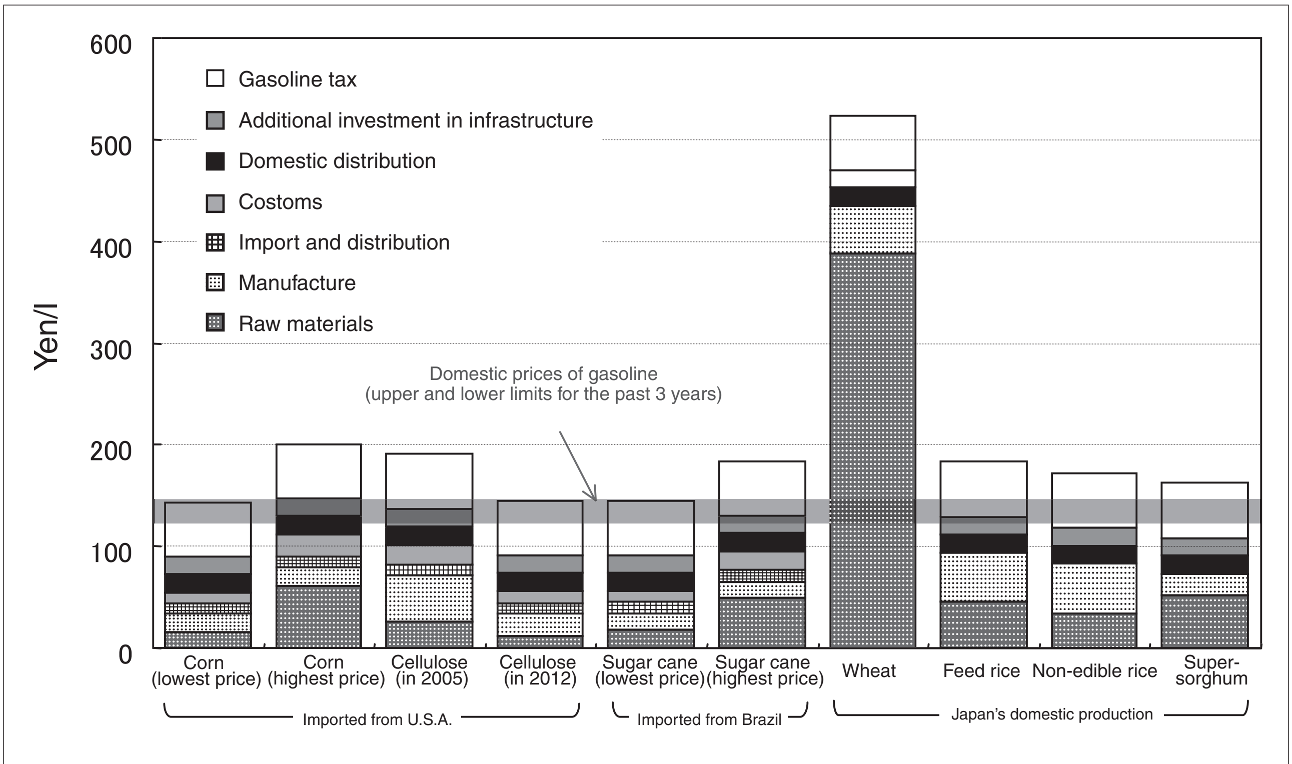


**Figure 5** : Breakdown price comparison between import and domestic production of bio-ethanol in Japan

[Assumptions used in the calculations]

i) Corn produced in the U.S.A.: The upper and lower limits of the prices for ethanol produced in the U.S.A. (free on oil tank yard) for the past 3 years. Plant capacity: 263 thousand kl/year. Ethanol made in U.S.A was transported by 1.9 DT chemical tankers. $1 = ¥120. Alcohol customs tariff: 23.8%.

ii) Cellulose produced in the U.S.A.: The costs for raw materials and manufacture are based on the real prices in 2005 and the US Dept. of Energy target values for 2012. The other values are as in Item i) above.

iii) Sugar cane produced in Brazil: The upper and lower limits of the prices for ethanol imported from Brazil (free on oil tank yard) for the past 3 years. The other values are as in Item i) above.

iv) Domestic wheat and feed rice: The costs for raw materials are based on the statistics provided by the Ministry of Agriculture, Forestry and Fisheries. Plant capacity: 36 thousand kl/year.

v) Non-edible rice: Based on a large-scale production model on a reclaimed land located in the Prefecture of Mie. The unpolished-rice harvest process was used. Rice hulls and straw were effectively used. The manufacturing costs are based on the US Dept. of Energy target values for 2012 as in Item ii) above.

vi) Super-sorghum: High-yield "ultra-sorgo" based on Reference[20]. The manufacturing costs are based on the US Dept. of Energy target values for 2012 as mentioned in Item ii) above.

Prepared by the STFC based on References[17-20]

is mass-produced domestically (at a price of 15 yen/kg) and if effective technologies for using the lignocellulose in the whole rice plant are developed, it is estimated that the price (without gasoline tax) for ethanol produced domestically from non-edible rice may be sufficiently competitive with the price of gasoline. Thus, the supply of domestic ethanol will be achievable on an economic and profitable basis, if Japan can satisfy the requirements for ethanol production already prevailing in the U.S.A. and Europe; these include "innovative technologies for conversion of biomass into ethanol", "the large-scale production of raw materials" and "fuel tax incentive system".

However, realistically, the ability of Japan to satisfy the requirements for the agricultural lands required for the large-scale production of raw materials, is limited[10]. The total area of unused agricultural lands which could be available to cultivate energy crops is 390 thousand ha (Table 5), of which about 80% is in small scattered lots not greater than 5 ha in size[21].

To achieve large-scale introduction of biofuels into Japan, the importation of overseas-produced ethanol must also be considered. However, it should be noted that the ethanol price volatilities in the U.S.A and Brazil have been extremely large, compared with the gasoline prices, for the past three years. The reasons must be that raw materials for ethanol production are limited to corn in the U.S.A and to sugar cane in Brazil, that the production of these materials depends on regional weather conditions and natural disasters, and the prices of these materials are liable to be volatile as speculation-driven futures markets. In the U.S.A., R&D efforts have been actively made to develop second-generation biofuel technologies in order to diversify the range of raw materials, including lignocellulose, for ethanol production and consequently to ensure a stable supply of biofuels at a cost comparable to that for corn-based ethanol.

From the short-term viewpoint of energy security, it is important for Japan to make efforts to develop and diversify domestic energy resources, such as improving the use of conventional fossil fuels, and increasing Japanese interests for developping overseas agricultural land for energy crops. To secure the projects in overseas, there is a long-term need for Japan to increase R&D efforts in developing its own second-generation biofuel technologies that cannot be provided by other countries, especially those rich in biomass resources.

## 3 Trends and problems in the development of second-generation biofuel technologies

This chapter describes trends in the R&D efforts aimed at overcoming the major barriers to the development of second-generation biofuel technologies. The R&D areas can be roughly classified into following 3 types.

**Table 5** : Land use in Japan

| | | | | | |
|---|---|---|---|---|---|
| Mountainous lands | 25 million ha | Natural forests | 15 million ha | | |
| | | Artificial forests | 10 million ha | Forests in service | 3.3 million ha |
| | | | | Unused forests | 6.7 million ha |
| Flat lands | 13 million ha | Agricultural lands | 4.7 million ha | Paddy fields | 1.6 million ha |
| | | | | Production-adjusted land | 1.0 million ha |
| | | | | Non-paddy fields and pastures | 2.1 million ha |
| | | Lakes, ponds, rivers and channels | 1.3 million ha | | |
| | | Roads | 1.3 million ha | | |
| | | Housing lands | 1.8 million ha | | |
| | | Others (including 0.39 million ha of unused agricultural lands) | 3.9 million ha | | |

Prepared by the STFC based on References[22-23]

### *3-1 Energy crop production technology*

Energy crops can be roughly classified into cereals, herbage (soft biomass), woods (hard biomass) and oil plants and can be compared in terms of dry matter yield per unit area of land. Within each of these classifications there are several candidates for use as energy crops (Table 6). Unlike edible crops, energy crops are primarily required to maximize dry matter yields per unit input of energy used to grow the crop with the lowest possible production costs; they do not need to satisfy any requirement for taste, color or shape quality. To minimize the competition for land between energy crop and edible crop production, it is assumed that energy crops can be produced on less fertile lands than edible crops. There is a large accumulation of research on increasing the production of edible crops and improving their resistance to adverse environmental influences. However, whether or not this accumulated knowledge can be effectively used for the production of energy crops is likely to depend on the weather and soil conditions of agricultural lands supposed to use for energy crops. It is unlikely that energy crops can be produced on the lands that suffer

**Table 6** : Representative energy crops and research and development trends

| Classi-fication | Variety | Dry yield [ t / ( ha • year )] | Research trend |
|---|---|---|---|
| Sugar and starch crops | Sugar cane (Sorghum) | 64.1 (Tropical, Hawaii)<br>49.5 (Subtropical, Okinawa)<br>28.8 (Temperate, Nagano) | Increasing the production of sugar by gene modification (Asahi Breweries, ltd., and National Agricultural Research Center)<br>Improving resistance to environmental stresses (SCIVAX Co., ltd.) |
| | Corn | 34.0 (Temperate, Italy) | Deciphering the genome (US DOE/DOA)<br>Developing hybrid varieties containing easily decomposable cellulose (Edenspace System Corp., US) |
| | Rice | 19.2 (Temperate, Iwate) | Deciphering the genome (Japan and China)<br>High-yield rice cultivars (Japan) |
| | Potato | 9.0 (Temperate) | Improving resistance to environmental stresses by gene transfer (Toyobo Co. , ltd.); conferring resistance to blight (Toyota Central R&D Labs., Inc.); and deciphering the genome (US DOE/DOA) |
| Vege-table oil crops | Palm (oil palm) | 20.0 (Tropical) | |
| | Rape | 1.4-2.5 (Temperate) | Increasing the production of unsaturated fatty acid by gene modification (The Dow Chemical Company /U.S. NRC) |
| | Soybean | 1.8-2.3 (Temperate) | Increasing the production of unsaturated fatty acid by gene modification (Suntory , ltd.)<br>Deciphering the genome (US DOE Joint Genome Institute)<br>Analyses of the proteome and metabolome (Australia) |
| Herbage | Napier grass | 84.7 (Tropical, Puerto Rico) | |
| | Guinea grass | 48.8 (Tropical, Puerto Rico)<br>51.1 (Subtropical, Okinawa)<br>24.3 (Temperate, Kumamoto) | |
| | Switchgrass | 16.0 (Temperate, U.S.A.) | Deciphering the genome (US DOE) |
| | Giant Miscanthus | 60.0 (Temperate) | Development of a hybrid varieties, euralia genus, rice family (Illinois University, US) |
| | Others | | Methods for growing a variety of perennial herbs in devastated agricultural lands (Minnesota University, US) |
| Trees | Poplar | 15-22<br>(Temperate, U.S.A and Ireland) | Deciphering the genome (US DOE Joint Genome Institute / Oak Ridge National Laboratory) |
| | Eucalyptus | 10-30<br>(Tropical and subtropical) | Cultivation in acidic soils (Oji Paper Co., ltd.) |
| | Japanese white birch | 7.4-10.8<br>(Subarctic, Hokkaido) | |
| | Willow | 19.0-20.5 (Hokkaido) | |
| | Japanese cedar | 4-7 (Hokkaido) | |

Prepared by the STFC based on References[4,24-29] from extremely dry weather and those that are deteriorated by salt contamination. On the contrary, lands selected as candidates for energy crop production require soils which are not too acidic or alkaline soils and which have a reliable precipitation level. It is expected that unused agricultural lands which can meet these requirements exist around the world. In the future, it is urgently necessary for Japan to establish the requirements (in terms of weather and soil) that domestic and international lands must be suitable for production of energy crops, and to identify the targeted lands that meet these requirements for efficient research activity.

There are two main research areas of improving energy crop dry matter production.

One is the molecular biological approach to understanding the nutritive mechanisms of crops in research conducted to improve plant varieties so as to be adaptable to deteriorated lands. Recently, a research team in the University of Tokyo investigated the nutritive mechanism of iron in deteriorated soil, and published a report on the development of a high-productivity crop by gene modification. The report attracted widespread attention[23].

The second approach is to improve the suitability of varieties of crops for use in commercializing the technology used to convert lignocellulose into ethanol. Specifically, research in the U.S.A. has actively focused on increasing the dry matter yields of cereal plants other than their edible parts and on modifying the structures of plants to make them more easily converted to ethanol.

### *3-2 Lignocellulose-to-ethanol conversion technologies[3,4]*

To manufacture bio-ethanol fuels from lignocellulose, it is necessary to add several processes to treat the plant material before the fermentation step used to produce ethanol (Figure 6). These processes are required to produce the starches and saccharides that are fermented into ethanol and include pre-treatment to unravel plant fibers, a process to convert cellulose and hemicellulose to saccharides (saccharification), and a process to remove lignin unnecessary for the fermentation to ethanol.

Sugar provided by conventional sugar and starch crops consists mainly of C6 saccharides such as glucose. If lignocellulose is saccharified, however, the product contains C6 saccharides and C5 saccharides such as xylose in the ratios of 2:1-3:1. Some of the conventional ferments have the disadvantage of not being able to ferment C5 saccharides, while others may restrict the fermentability of C5 saccharides in the presence of C6 saccharides. Thus, the conventional technologies cannot effectively use the saccharic

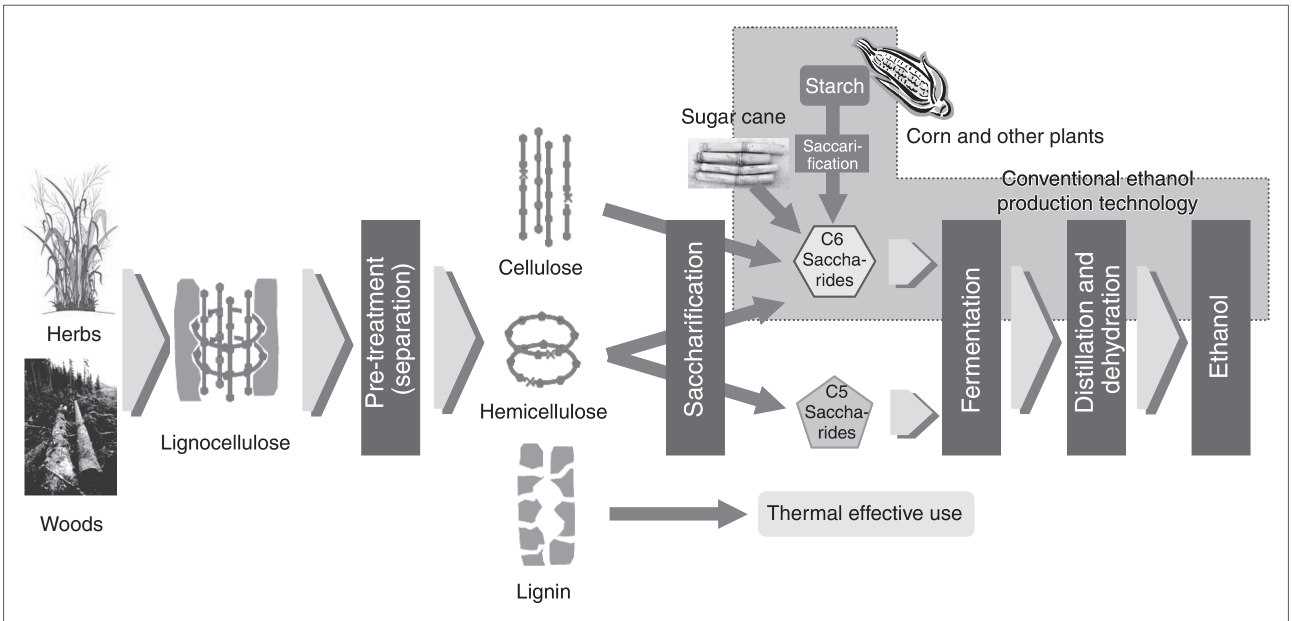


**Figure 6** : Lignocellulose-to-ethanol conversion processes

Prepared by the STFC based on References[4,10] components of lignocellulose.

As a result, present commercialized technologies cannot produce lignocellulose based bio-ethanol fuels in a manner competitive with fossil fuels in terms of energy efficiency, production costs and environmental load.

In reviewing various technologies for converting lignocellulose into ethanol, the key factors in identifying and optimizing the best technology are (1) higher efficiency and lower cost of the pre-treatment and saccharification processes and (2) higher efficiency in the fermentation process. Therefore, these factors have been reviewed (Table 7).

To achieve the twin goals of higher efficiency and lower cost of the pre-treatment for the saccharification processes, the conventional acid hydrolysis process is being replaced with a promising new technique, “enzymatic saccharification” (Figure 7). The new technique can decompose cellulose by using specific enzymes, cellulases, under moderate conditions

**Table 7** : Research on second-generation conversion technologies for lignocellulose-based ethanol fuels

| Item | Research subject | Research institution | Research stage |
|---|---|---|---|
| Pre-treatment | Alkali treatment/lignin solubilization and removal | Forestry and Forest Products Research Institute (Japan) | Basic research |
| | Acidic treatment and non-crystallization of cellulose / separation of saccharides from hemicellulose / lignin removal by organosolation | Virginia Polytechnic Institute and State University (USA) | Basic research |
| | Lignin decomposition with white rot bacteria | Joint Genome Institute (USA) and Kyoto University (Japan) | Basic research |
| Saccharification | Saccharification and double-fermentation in parallel with on-site production of enzyme | University of Tokyo (Japan) and Lunds University (Sweden) | Basic research |
| | Production of enzyme by solid fermentation | University of Tokyo / Riken (Japan) | Basic research |
| | Production of different kind of enzyme with different species of bacteria | Kobe University / Gekkeikan Sake Co., ltd. (Japan) | Basic research |
| | Production of enzyme with gene-modified microbes (Trichoderma reesei) | Iogen Corporation (Canada) | Trial production |
| | Integration of pre-treatment and saccharification by steam/subcritical/critical water processing | Kyoto University (Japan) and British Columbia University (Canada) | Basic research |
| Fermentation | CO2 removal & on-line product separation | Kyowa Hakko Kogyo Co., ltd. (Japan) | Demonstration |
| | Simultaneous fermentation of C5/C6 saccharides by a gene-modified ferment | Pardue University (USA) / Iogen Corporation (Canada) | Trial production |
| | Fermentation of C5 saccharides with Pichia ferment and Zymomonas bacteria | Akita Research Institute for Food and Brewing (Japan), Tottori University (Japan) and NREL (USA) | Basic research |
| | Simultaneous saccharification and fermentation with cellulase, glucosidase gene-linked ferment on cell wall surface, and cellulase gene-transferred bacteria | Kyoto University / Kobe University (Japan) Dartmouth College / Mascoma Corporation (USA) | Basic research Demonstration |
| | Fast fermentation with yeasts resistant to heat and ethanol produced by gene modification | Massachusetts Institute of Technology (USA) | Basic research |
| Separation & concentration | Reduction of energy consumption by zeolite separation membranes | Kyowa Hakko Kogyo Co., ltd. (Japan) | Demonstration |
| | Continuous production with concentration switching membranes | National Agriculture and Food Research Organization / University of Tokyo (Japan) | Basic research |
| Production of by-products | Liquidation and conversion of cellulose and lignin | Department of Agriculture in University of Tokyo, Forestry and Forest Products Research Institute, and Kyoto University (Japan) | Basic research |
| | Production of valuable by-products from lignin | STFI-packforsk AB / Chalmers tekniska högskola / LignoBoost AB (Sweden) | Trial production |
| | Production of organic acid & polyhydric alcohol with separated bio-reactor | Argonne National Laboratory / Archer Daniels Midland Company (USA) | Basic research |

Prepared by the STFC based on references[28-29,31-33] to produce saccharides, and are more energy efficient than acid hydrolysis. Strains of bacteria which could produce useful cellulases have been detected among the bacteria present in the internal organs of plant-eating animals and the bodies of white ants. Fungi producing cellulases are common in leaf mold. Gene modification technologies have been used in attempts to improve the efficiency of enzyme production[3].

The discovery of the cellulosome, an exocellular multiprotein complex specialized in cellulose degradation, lead to research becoming increasingly focused on the use of gene modification technology in the creation of complex plural enzyme function modules required in the cell wall decomposition process[37].

To achieve a higher efficiency in the fermentation process, ferments which can simultaneously ferment C5 and C6 saccharides have been subjected to gene modification technology linking a sacharifying enzyme with the surface layer of a second enzyme, with the aim of developing ferments which have a high resistance to ethanol and heat, and which can simultaneously undertake both saccharification and fermentation.

In the U.S.A. greater importance has been attached to the use of molecular genetics (Figure 8) to rapidly improve the productivity and reduce the cost of using enzyme technologies (Figure 9). To obtain new useful microbes, enzymes and metabolic routes, and to establish the enzymatic hydrolysis method, R&D efforts have been actively made to understand the genome/protein/metabolic mechanism linkages and to create a database of these mechanisms by using rapid analyzers and simulation techniques.

For example, a large enzyme manufacturer and the National Renewable Energy Laboratory (NREL) in the U.S.A published a report on the results of research aimed at understanding the interaction of cellulose and the enzyme (cellulase), particularly the active point of decomposition in the high-order structure of cellulose, with the intention of producing more active cellulases at a lower cost[16]. Today, a venture business supported by the US Department of Energy (DOE) is conducting preliminary testing prior to launching into the

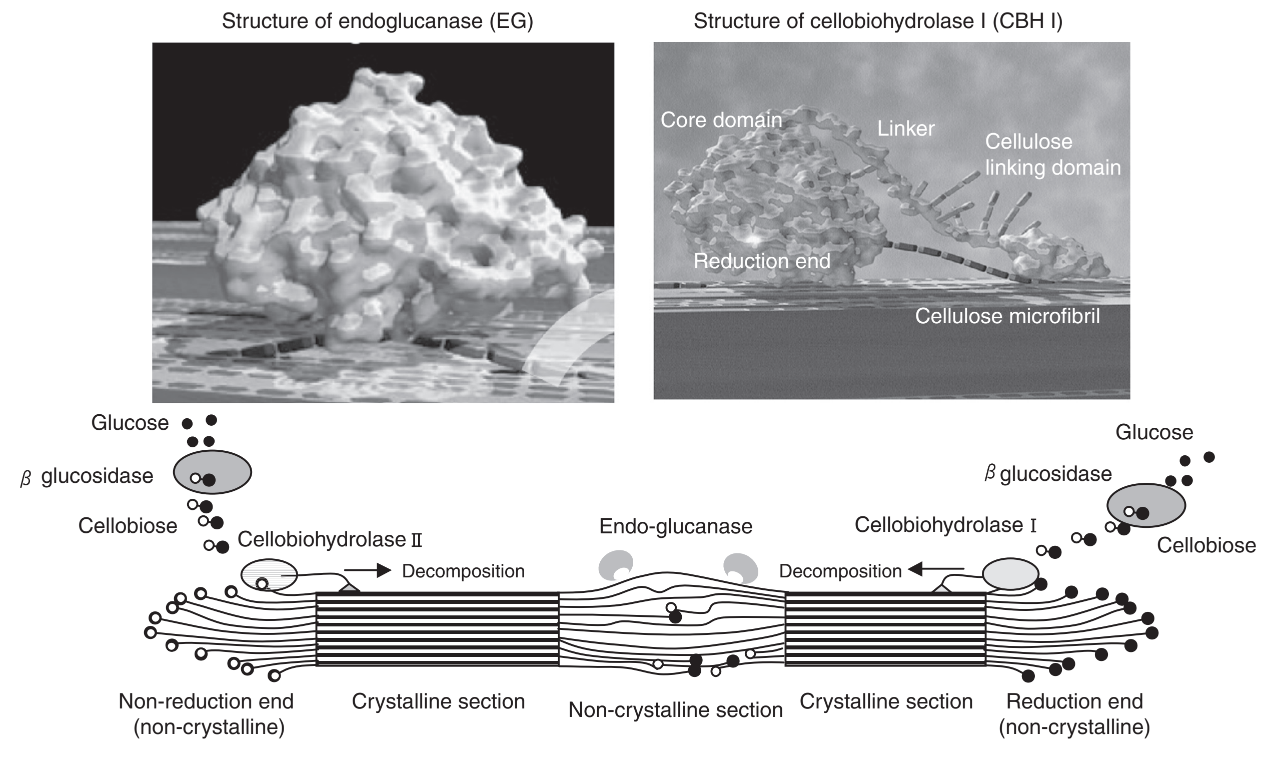


**Figure 7** : Cellulase enzymes and the bio-chemical cellulose decomposing mechanism

Prepared by the STFC based on References[3,34-35]

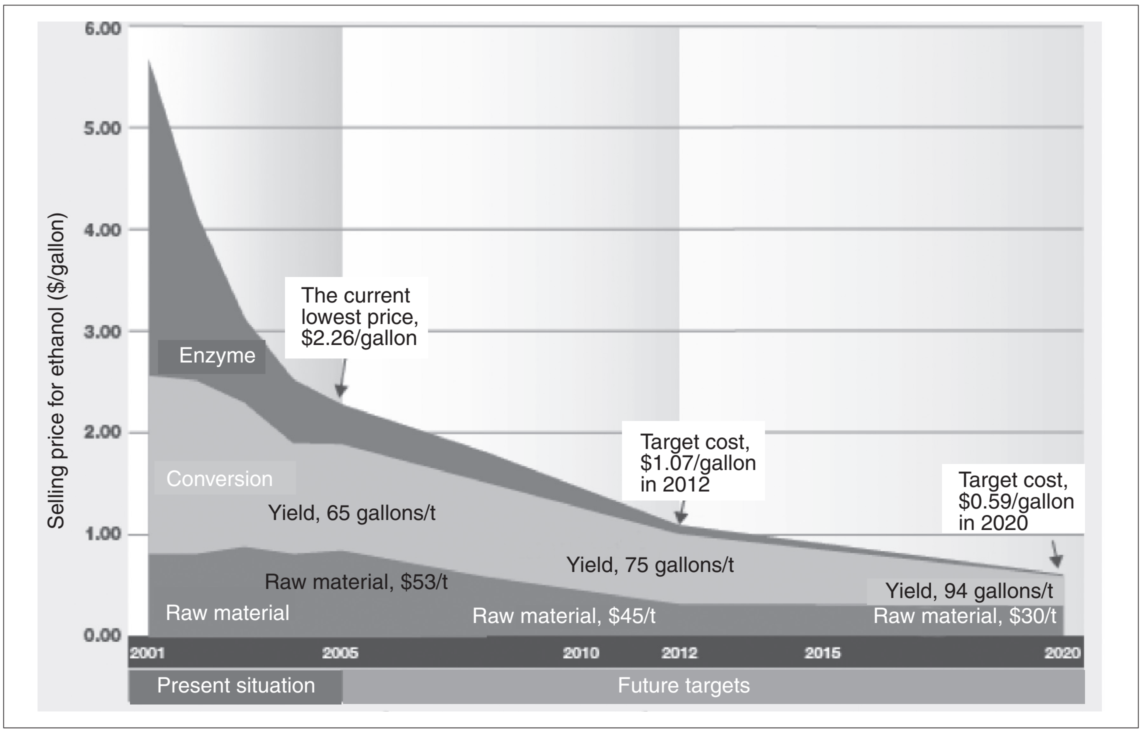


**Figure 8** : US Dept. of Energy target costs for cellulosic ethanol

From Reference[36]

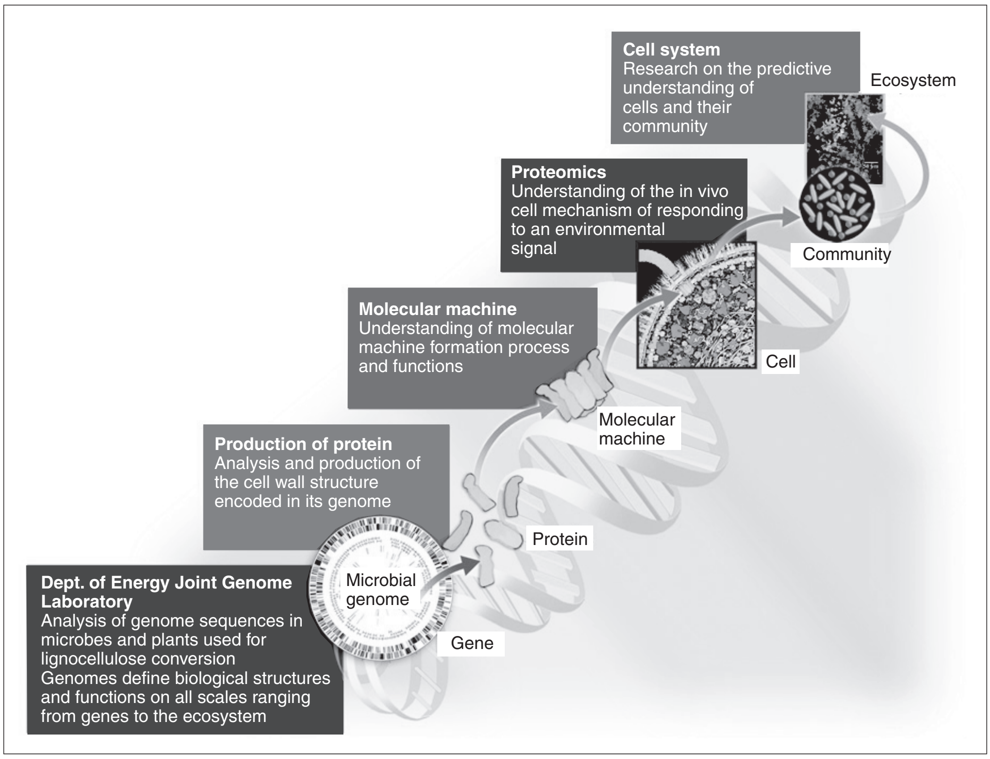


**Figure 9** : Molecular biology research on bio-ethanol production in the U.S.A (DOE)

From Reference[36]

industrial production of cellulase and cellulosic ethanol. The knowledge obtained from these R&D efforts is now being fed back into the research aimed at improving plant varieties so that they are more easily decomposed.

### 3-3 Bio-diesel fuel-related technologies

Fatty acid methyl ester (FAME) produced from plant oils is now used as a bio-diesel fuel (BDF) and is actively commercialized, mainly in Europe and East South Asia. However, FAME has disadvantages in that it is prone to oxidization

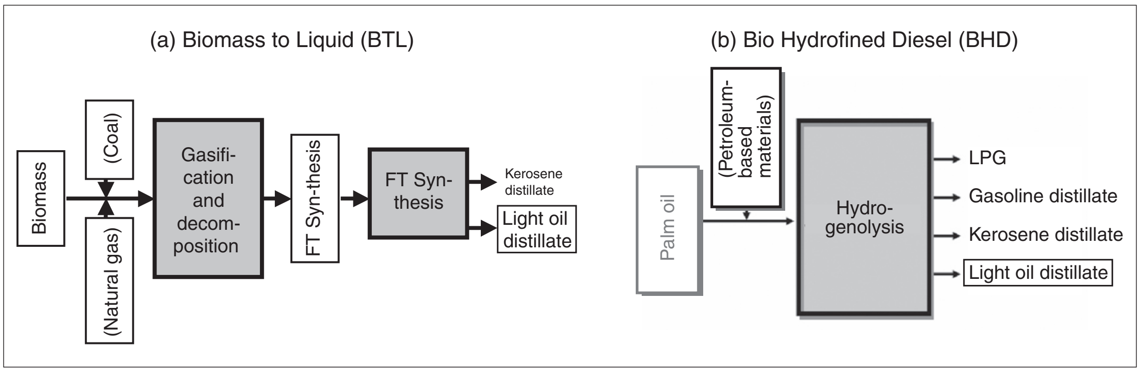


**Figure 10** : Comparison of the two second-generation bio-diesel fuel technologies

Prepared by the STFC based on Reference[38]

and it has a low stability during storage. In addition, the properties of this fuel depend on the source plant oils and fat materials used in its manufacture. Some materials are so easily solidified that they cannot be used during winter in regions at medium and high latitudes. Thus, FAME presents many disadvantages in terms of distribution, which prevents the widespread use of this fuel.

In developing second-generation biofuel technologies, the main challenge is to convert a variety of plant oils and fat materials into BDF that has stable properties. The second-generation BDF technologies which are now proposed are roughly divided into 2 types, Biomass to Liquid (BTL) and Bio-Hydrofined Diesel (BHD) (Figure 10). In recent years, the industrial practicality of BHD technology has been demonstrated and the technology is approaching the commercialization stage earlier than the lignocellulose-to-ethanol conversion technology.

## *3-4 Comparison of research trends in countries by analysis of published research papers*

The number of scientific and technological papers published on biofuel-related technologies has rapidly increased in all countries since 1990. The number of papers published on research on ethanol, BDF and energy crops has been highest in the EU-15 countries and the U.S.A. (Figure 11). The difference between the number of publications of the EU-15 countries and the U.S.A. and that of all other countries has rapidly increased, especially since the 1990s. In the U.S.A., the amended Clean Air Act, which stipulates the obligation of adding oxygen-containing compounds to vehicle fuels to reduce carbon monoxide emissions, was enforced in 1990 and since then the demand for ethanol has rapidly increased[39]. It is apparent that this act was a major factor influencing the increase in research activity into biofuels since the 1990s.

In China, the number of papers published has increased rapidly since 2000. As a result, the number of papers published on research on bio-ethanol, BDF and energy crops was higher in 2006 in China than in Japan. In China, priority has been given to research and development of biofuels under the “National Project for High-Technology Research and Development Program of China (863 Program)”, implementation of which started in January 1986[40]. Under the “Ethanol-Mixed Gasoline Development Project” introduced in the “10$^{th}$ 5-Year Plan” in 2001, a model project for introducing ethanol-blended gasoline was implemented and the law supporting the project was established. Under the “11$^{th}$ 5-Year Plan” in 2006, renewable energy development was introduced as the priority area in the National Energy Strategy. The Chinese Government also enforced the “Renewable Energy Law of the People’s Republic of China” in 2006, ahead of the other Asian countries, and the policy of raising the share of renewable energy, especially biomass, up to 16% of the total supply of primary energy by 2020 was established under the “Middle and Long-Term Development Plan of Renewable Energies”[41]. In this context, it is probable that research on biofuels will become increasingly active in China.

In Brazil and Canada, research is focused on mainly bio-ethanol production. In recent years, however, research on BDF has also been more

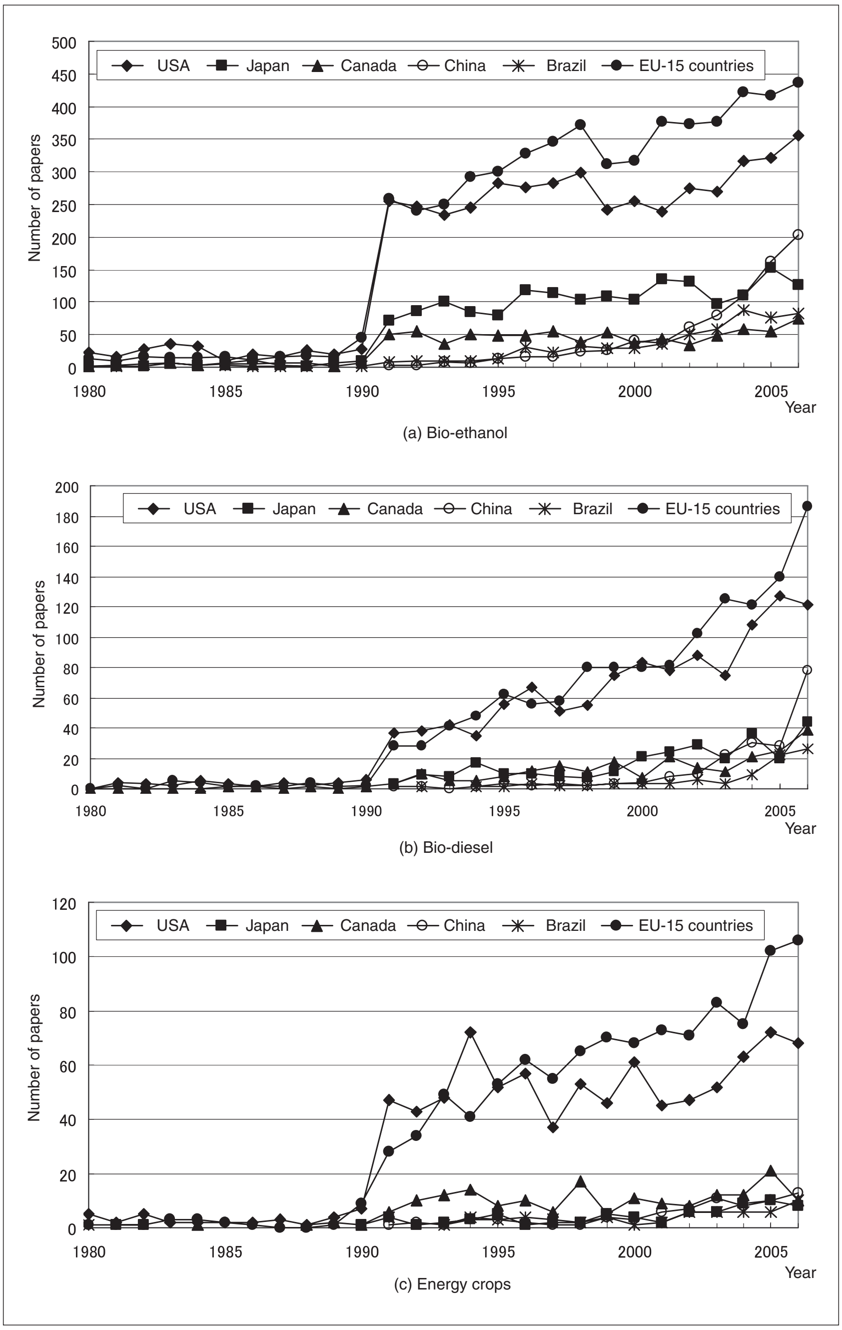


**Figure 11** : Number of scientific and technological papers published on biofuel-related technologies by country

The data shown in the charts were calculated by the National Institute of Science and Technology Policy using Thomson Scientific's database "Web of Science".

actively pursued.

A comparison by region has been made in the number of papers published on the various disciplines in lignocellulose-to-ethanol conversion technologies. This shows that, while Japan, the U.S.A. and the EU are almost level pegging in the fields of chemical engineering and applied chemistry, the U.S.A. and the EU are outstripping Japan in the fields of biotechnology, molecular biology and microbiology (Figure 12). Although Japan was considered to be strong in the field of microbiology, especially fermentation[42,43], it has not applied this strength sufficiently to research on lignocellulose-to-ethanol conversion technologies.

The U.S.A. accounted for the majority of the research institutions that published the greatest numbers of papers in each field. However, it should be noted that Lunds University in Sweden and the University of British Columbia in Canada ranked above US research institutions in the field of lignocellulose-to-ethanol conversion technologies (Table 8). It is notable that the two universities have not only conducted advanced

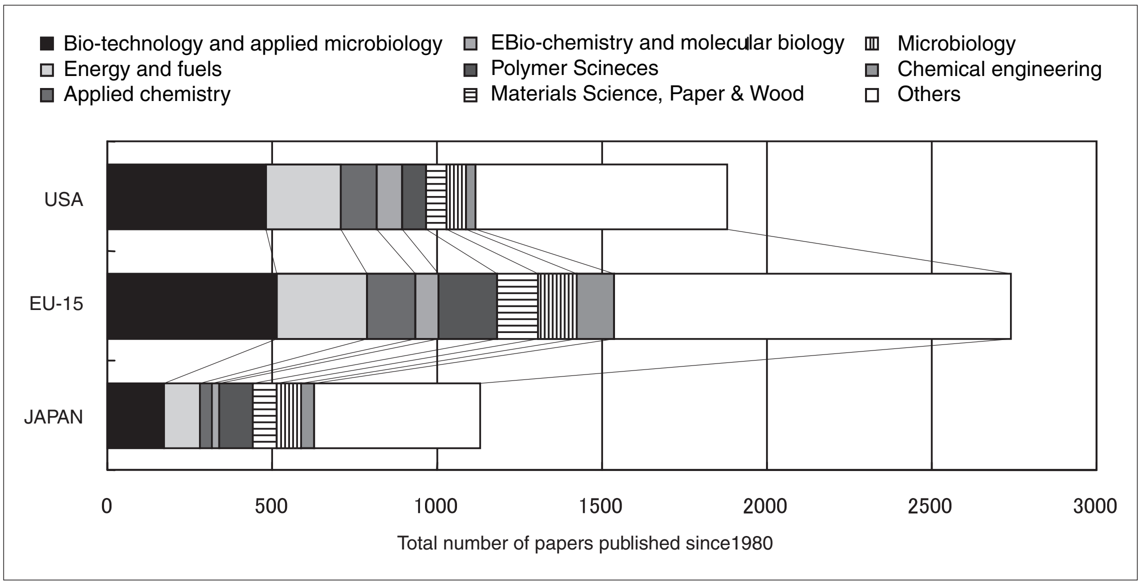


**Figure 12** : Comparisons of the number and fields of papers published in each country on lignocellulose-to-ethanol conversion technologies

**Table 8** : Ranking of biofuel-related research institutions in the total number of papers published since 1980

| Ethanol (lignocellulose) | | | | Bio-diesel | | | | Energy crops | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Research institution | Country | Number of papers | Rank | Research institution | Country | Number of papers | Rank | Research institution | Country | Number of papers |
| 1 | Lunds University | Sweden | 132 | 1 | Indian Institute of Technology | India | 55 | 1 | DOA, Agriculture, Science and Education Administration | USA | 153 |
| 2 | British Columbia University | Canada | 101 | 2 | Chinese Academy of Science | China | 46 | 2 | National Institute for Agricultural Research (INRA) | France | 83 |
| 3 | DOA, Agriculture, Science and Education Administration | USA | 97 | 3 | DOA, Agriculture, Science and Education Administration | USA | 45 | 3 | Swedish University | Sweden | 52 |
| 4 | Russian Academy of Science | Russia | 69 | 4 | US Department of the Environment | USA | 40 | 4 | California University, Davis School | USA | 45 |
| 5 | National Renewable Energy Laboratory (NREL) | USA | 64 | 5 | Nebraska University | USA | 35 | 5 | Oak Ridge National Laboratory | USA | 42 |
| 6 | Kyoto University | Japan | 63 | 6 | Texas University | USA | 34 | 6 | Texas A&M University | USA | 37 |
| 7 | National Institute for Agricultural Research (INRA) | France | 61 | 7 | California University, Barkley School | USA | 29 | 7 | DOA, Agricultural Research Service | USA | 36 |
| 8 | University of Tokyo | Japan | 57 | 8 | Kyoto University | Japan | 26 | 7 | Chinese Academy of Science | China | 36 |
| 9 | Chinese Academy of Science | China | 51 | 8 | Athens Institute of Technology | Greece | 26 | 7 | Florida University | USA | 36 |
| 10 | Cornell University | USA | 50 | 8 | Idaho University | USA | 26 | 7 | University of Reading | UK | 36 |

Calculated by the National Institute of Science and Technology Policy using Thomas Scientific's database "Web of Science".

research, mainly on woody lignocellulose-based energy crops, but also have become key centers for cooperation in the fields of energy and life sciences by establishing partnerships with industry and other research institutions interested in biomass utilization systems. It is also notable that the Indian Institutes of Technology and the Chinese Academy of Sciences have ranked above most other research institutions in the field of BDF related technologies.

## 4 Challenges facing Japan's R&D initiatives

It is essential that worldwide research on innovative second-generation biofuel technologies is based on knowledge in the life sciences field, especially molecular biology and crop nutrition (Table 9). It must be noted that Japanese research in the energy field has not been based on active

**Table 9** : Research on biofuels requiring a knowledge of life sciences

<table>
<tr><th colspan="2">Field of research</th><th>Goal</th><th>Research subject</th><th>Theme of research</th><th>Required resources and bases</th></tr>
<tr><td rowspan="2">Production of microbes</td><td>Fermentation</td><td>Rapidly improved fermentation productivity</td><td>Primary and secondary metabolic products<br>Synthetic intermediates and other in vivo components</td><td>Identifying new useful microbes<br>Identifying new useful enzymes/group of enzymes/metabolic routes<br>Establishment of high-level manifestation control methods<br>Establishing high-level metabolism control methods<br>Establishing methods for control of cell/organism interactions<br>Establishing feed-back control methods<br>Accelerating cell proliferation and metabolic rates<br>Establishing a rapid no-/low-oxygen fermentation</td><td>Rapid analysis of trace compounds in complex systems<br>Analyses of chronic and continuous transcription and metabolism<br>Analysis of phenomena in single cells<br>Understanding of all protein synthesis and control mechanisms in specific strains of bacteria<br>Understanding of cell/organism interactions<br>Understanding of feedback response mechanism<br>High-efficiency gene manipulation technologies, database for microbial genome/protein/metabolic interactions, metabolism/fermentation simulation technologies, instrumentation and control technologies, and separation and refining technologies</td></tr>
<tr><td>Production system</td><td>Increased use of bio-energy at low cost</td><td>Crop ecosystem environment</td><td>Community genomics<br>Understanding of microbe interactions in non-sterile systems<br>Eco-system control</td><td>Meta-genome, meta-transcriptome<br>Super-trace substance identification equipment<br>Ecosystem structure analysis and simulation technology</td></tr>
<tr><td rowspan="2">Productivity of plant</td><td>Agricultural products</td><td>Increased yield</td><td>Energy crops (cereals, beans, potatoes, oil and fat plants)</td><td>Understanding of crop properties on genome basis<br>Heterosis, reproductive isolation, and sink -source transition functions<br>Resistance to stresses and adaptability to the environment<br>Organism interactions (parasitism, symbiosis, mycorrhiza ,bacteria and soil microbes)<br>Genome level analysis of the growth process<br>Transfer of useful genes into crops</td><td rowspan="2">Genome data<br>Wild resources<br>High throughput screening methods<br>Metabolome and proteome<br>Mating groups for QTL analysis<br>Open systems for the evaluation of gene-modified crops<br>Genetic control manifestation control for plants<br>Plant factories</td></tr>
<tr><td>Production by trees and herbage</td><td>Increased yield of plants</td><td>Lignocellulose</td><td>Efficient sequential process for the conversion of lignin<br>Conversion and separation of wood components<br>Deciphering of cycle design for plant material<br>Understanding of biosynthetic systems and biosynthetic control systems<br>Development of bio-component conversion methods (in cooperation with the field of microbiology)<br>Production of cellulose decomposing systems (hydrolysis to saccharides) using fermentation</td></tr>
</table>

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exchange and cooperation with researchers in the life sciences field.

Under the 3rd Science and Technology Basic Plan, biomass related technologies have been selected as the priority subject in the science and technology strategy for the environmental field. The Council for Science and Technology Policy has prepared a series of partnership measures for biomass, and is committed to promoting partnerships and the exchange of information between biomass-related Ministries and Agencies. With respect to individual themes in biofuels R&D, cooperation and partnerships between research areas has not been sufficiently ongoing. The main public research institutions working on biofuels participate in the "Council for Promotion of Biofuels Research" established in April 2007[44], and it is expected that these participants will have an important role in promoting communication and cooperation for enhancing their multidisciplinary research areas.

## 5 Conclusions and Recommendations

In recent years, R&D efforts, mainly in the U.S.A. and Europe, have focused on (1) the development of "energy crops" as the basis for alternative transport fuel resources and (2) the "energy crop-to-biofuel conversion technologies", in order to reduce the medium- and long-term dependence on fossil fuels. This paper has described the potential biofuel alternatives to conventional petroleum in Japan in terms of quantity and cost. The important points are summarized as follows:

- It is expected that competition between energy crops and edible crops will be most intense in 2050 when the world population is expected to reach its peak. The possible supply of ethanol was estimated on the basis of realistic predictions on the increase in the total area of agricultural lands and on the demand for cereals. The results indicate that the potentially useable land available worldwide will be enough to satisfy both the demand for foods from the world population and the demand for biofuels.
- If the requirements for "innovative technologies for conversion of biomass into ethanol", "the large-scale production of raw materials" and "fuel tax incentive system" can be satisfied, it will be possible for Japan to supply domestic biofuels that are cost competitive with gasoline at the current price and with biofuels produced overseas. However, based on a realistic view of land use in Japan, it should be foreseen that the supply of domestic biofuels will be quantitatively limited.
- If Japan imports overseas-produced biofuels, the prices for the imported biofuels may be competitive with the current price of gasoline on the condition that fuel tax incentives are implemented. However, because of the large price volatilities of overseas produced ethanol, imported biofuel prices may not always be competitive.To diversify the raw materials supply, R&D efforts are being made throughout the world to develop second-generation biofuel technologies. Paying attention to these moves, Japan should also make efforts to develop its own second-generation biofuel technologies.

Based on these points, we make the following recommendations on the Japanese challenges in the research and development of second-generation biofuel technologies:

### i) Preparation of a national biofuels introduction strategy and a roadmap for research and development of second-generation biofuel technologies and facilitation of the linkage between them

To introduce biofuels into the Japanese transport sector, it is essential to use domestic biomass resources most effectively. However, realistically, it is expected that the supply of biofuels domestically produced at costs comparable to those for fossil fuels will be quantitatively limited. Therefore, it will be necessary to make efforts to acquire Japanese interests in the exploitation of the increasing areas of overseas lands cultivated for energy resources. To secure the projects in overseas, it is necessary for Japan to develop its own second-generation biofuel technologies that will be regarded as valuable by overseas countries rich in biomass resources. The Japanese Government also is required to set both national quantitative targets and the time frame for the introduction biofuels. It should also prepare a resources strategy based on the balance between overseas and domestic biomass resources, review related policies and systems (such as the land use and agricultural policies, taxation incentives, and regulations); and prepare a roadmap for research and development of second-generation biofuel technologies, meeting the requirements mentioned above.

ii) Clarification of the requirements for lands to produce energy crops and the selection of research subjects

Energy crops require a greater emphasis on increasing productivity per unit input of energy and reducing production costs than edible crops. Therefore, research approaches will depend significantly on the conditions, such as weather and soil, pertaining in lands selected for producing energy crops. To avoid competition between the production of energy crops and the production of foods while at the same time achieving acceptable energy crop productivity, it is likely that the lands used for energy crops will be currently uncultivated and have acidic or alkaline soils and a reasonable precipitation level, but not be extremely dry or deteriorated by salinization. From the medium- and long-term perspectives, it is important to select as research targets technologies for producing energy crops that can be grown in the lands available for Japanese biofuel consumption.

iii) Cooperative multidisciplinary research in the fields of energy and life sciences required to develop second-generation biofuel technologies

Much of the worldwide research conducted on second-generation biofuel technologies is based on knowledge in the life sciences field, especially molecular biology and crop nutrition. Japanese research in the energy field has not been conducted in cooperation with researchers in life sciences, nor effectively used the accumulated knowledge in the field of microbiology, especially fermentation, where Japan is considered to be strong. In the future, therefore, it is important to more actively encourage exchanges of information and researchers in these fields. In addition, it is necessary to thoroughly investigate the factors responsible for successful industry-university partnerships in research centers in the U.S.A. and Europe, and to establish such partnership research centers in Japan and concentrate research resources on them. It is also necessary to actively invite researchers from other countries rich in energy resources to Japanese centers to conduct R&D into second-generation biofuel technologies, and to strengthen relationships between Japan and the other countries rich in biomass resources through the development of human resources and technological cooperation.

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5

# Technology Trends in Stock Management of Road Structures

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## 1 Introduction

In order to restore the country from the ravages of World War II and catch up with the advanced nations of North America and Europe, Japan has upgraded both the quality and the amount of its infrastructure. In particular, there is an enormous stock of social capital that was built up during Japan's period of high economic growth (1955-1973). The peak of its renovation period will come from about 2020 through 2030. Increasing investment in renovation, maintenance, and operation is a concern.

Road structures (broadly classified as bridges, tunnels, pavement, accessory facilities, and so on) constructed during the period of high economic growth currently account for about 34 percent of all bridges and 25 percent of all tunnels. Twenty years from now, the number of bridges on general national highways and regional roads that are at least 50 years old will total 64,000, eight times as many as in 2005, while the number of tunnels on the same roads that are at least 50 years old will triple, to 3,600. Furthermore, with the diversification of the people's needs regarding infrastructure, new issues such as responding to environmental concerns that have come to the fore, population decline, a low birth rate and a larger number of elderly people, and a difficult financial situation make renovation of aging infrastructure even more difficult. In order to efficiently maintain and manage infrastructure, shrink life-cycle costs, and ensure longer infrastructure life, as well as to avoid risks such as bridge collapses, infrastructure improvement through stock management that is responsive to social change is and will remain important.

The "Third Science and Technology Basic Plan" refers to stock management in the social infrastructure field. "With the large infrastructure constructed during the period of rapid economic growth rapidly aging, society's need for technology to operate, maintain, and renovate social infrastructure is growing. From the perspective of the public good, it is a research and development theme that the national government must address." First, it lists "optimization of the maintenance and renovation of social capital and structures."

This article gives an outline of elemental technology such as the background and issues requiring stock management, the deterioration mechanisms and phenomena necessary for stock management, inspection and diagnosis, evaluation of soundness, prediction of deterioration, and repair and reinforcement, and a bridge management system now under development. It then discusses the responses required as replacement periods approach.

## 2 What is stock management?

Asset management takes individual financial assets such as savings, stocks, and bonds, considers risk and profitability, and manages the assets appropriately in order to maximize their value. In recent years, real estate management has applied the same methods used to manage financial assets to the management of land and buildings in order to raise asset value.

The main terms employed in the management of assets are "asset management," "facilities management," "property management," and "stock management." These are generally used when speaking of "the integration of all processes involved in design, construction, operation and maintenance, repair, renovation, and so on that maximize user benefit and minimize supplier and user costs." Use of the term "asset management" is common in the roading sector, while "facilities management" and "stock management" are commonly applied to government facilities. "Social capital management" is used with a wide range of social capital. There are currently no clear definitions for these terms[1]. In the USA, which is advanced in terms of how it manages social capital, a variety of terms is also used without standardization of terminology.

Stock management related to road structures is divided into overall management that handles different kinds of road facility assets (e.g., pavement, bridges, tunnels, and retaining walls), like-asset management that handles one type of asset (e.g., pavement only or bridges only), and individual management that handles individual structures (e.g., a bridge in a certain location). Overall management and like-asset management require objective evaluation of service levels (management goals), while like-asset management and individual asset management must set the goal of minimizing life-cycle costs. At this point, however, research towards practical application is limited to "tangible" management systems such as like-asset management and individual asset management for bridges or pavement and so on.

## 3 Current conditions and issues

### *3-1 Current conditions and issues in Japan*

**(1) Social/economic conditions**

Japan's population is declining after peaking at 127.79 million in 2004. Estimates show the population declining to 100.6 million by 2050[2]. The more rural the area, the faster the population is declining. Furthermore, the birthrate is declining, falling to 1.25 in 2006. The percentage of elderly people aged 65 and older is projected to rise from 19.9 percent of the population in 2005 to almost 30 percent in 2030[2]. There is concern that in the future the shrinking labor force and the disappearance of rural communities accompanying the rapid advance of a low birth rate and a larger number of elderly people will make delivering basic social services difficult in some regions.

Looking at the construction industry, the number of people employed in construction continually increased along with the amount of money invested in construction until 1997, contributing to the stability of employment in Japan even during the long recession. Subsequently, however, investment in construction declined, and by 2005 the number of workers employed in construction fell to 5.68 million, about the same number employed in 1988. Because of the image of construction jobs as difficult, dirty, and dangerous, the decline in the number of younger people employed has been especially striking. The percentage of relatively older workers (age 55 and up) has increased and now accounts for 30 percent of the whole. This aging trend is stronger in the construction industry than in other industries. It is a significant problem in terms of the continuation and growth of the entire industry. Looking at the recent profitability of general contractors, payment of compensation for defects is placing downward pressure on profits. The causes appear to be structural issues in the construction industry, namely, increasing competition and decreasing technical ability[3]. Currently, many of the Japanese baby-boom generation's engineers and skilled technicians are approaching retirement. Finding enough younger workers and passing on technologies and skills are serious problems for the entire construction industry.

Public works expenditure including construction has played an important role in employment policy during the postwar recovery period and in economic policy following the period of high economic growth. Although government bond issues for construction temporarily increased as an economic policy following the collapse of the bubble economy, they are currently on a declining trend. However, with budget deficits rising, deficit-covering bonds are also increasing. In FY 2006, debt servicing accounted for about 38 percent of the general account budget of ¥79.7 trillion. Government finances may become increasingly constricted.

**(2) Condition of road structure stock**

According to Social Capital of Japan: Stock across Generations[4], edited by the Director

General for Economic, Fiscal and Social Structure of the Japanese Cabinet Office, there has been a rapid build up of social capital since 1970 in the period of high economic growth. (see Figure 1.) By type of social capital, transportation (roads, ports, aviation, railways) accounts for 40 percent, with living-related (water and sewers, parks, waste, public housing, postal services) accounting for 20 percent, agriculture, forestry, and fisheries industries (agriculture, forestry, fisheries, industrial-use waterworks) for 15 percent, national land conservation (forest conservation, flood control, beaches) for 13 percent, and education (schools, social education facilities) for 12 percent. The percentage of social capital related to transportation, which supports logistics and the economy, is high, with road-related infrastructure accounting for much of that. This indicates that into the future, road-related areas will require a large investment for operation, maintenance, and renovation.

As of April 2005, the combined length of national expressways, national and prefectural roads, and municipal roads was about 1.19 million kilometers. By management authority, former public corporations*1 account for about 7,000 km (1 percent), the national government for about 22,000 km (2 percent), prefectures for about 129,000 km (11 percent), and municipalities for about 1.02 million km (86 percent)[5]. Regional roads comprise about 97 percent of all roads, with around 89 percent of bridge locations and approximately 54 percent of tunnel locations.

Nationally, there are about 148,000 road bridges with lengths of at least 15 meters. Of these, the former public corporations manage around 6,000 (4 percent), the national government about 11,000 (7 percent), prefectures approximately 45,000 (31 percent), and municipalities roughly 86,000 (58 percent). By type, prestressed concrete bridges*2 account for 40 percent, steel bridges for 39 percent, reinforced concrete bridges*2 for 17 percent, and other types for 4 percent[5]. Figure 2 depicts the nationwide number of bridges and the number constructed. Bridges built during the intensive construction that occurred during

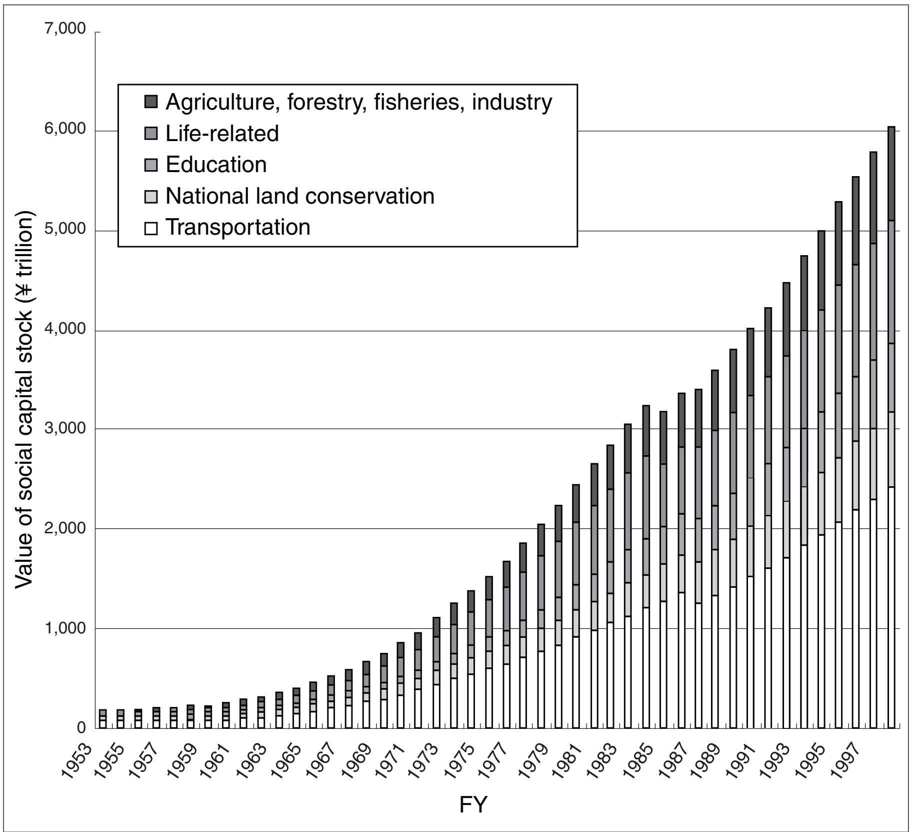



**Figure 1** : Value of social capital stock

Agriculture, forestry, fisheries industry (agriculture, forestry, fisheries, industrial-use waterworks), life-related (water and sewer services, parks, waste, public housing, postal services), education (schools, social education facilities), national land conservation (forest conservation, flood control, beaches), transportation (roads, ports, airports, railways)

Prepared by the STFC with reference to Reference[4]

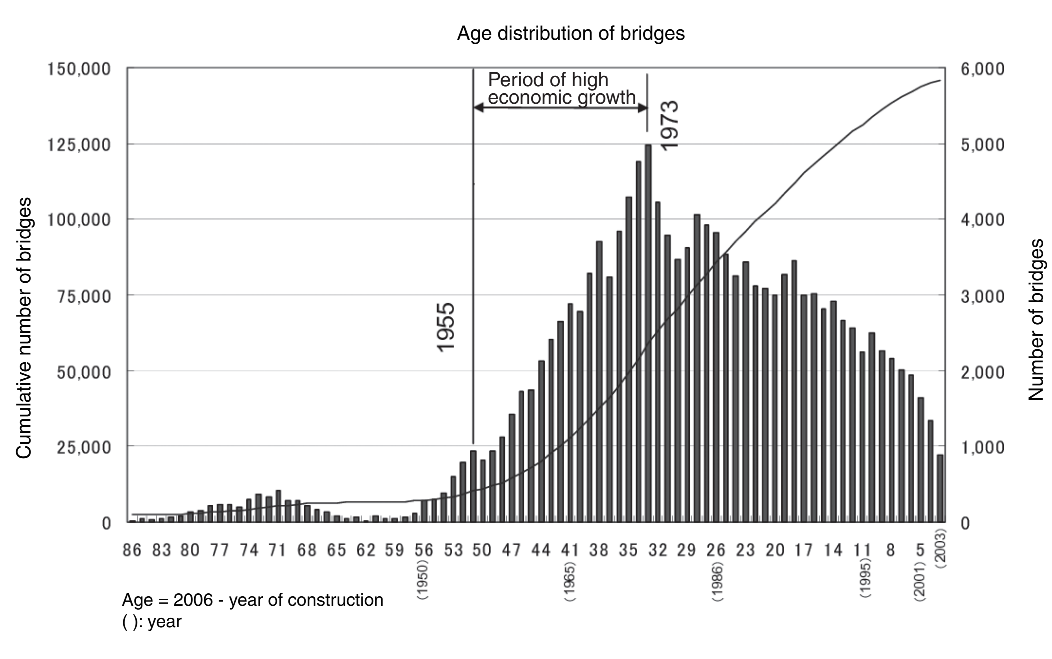
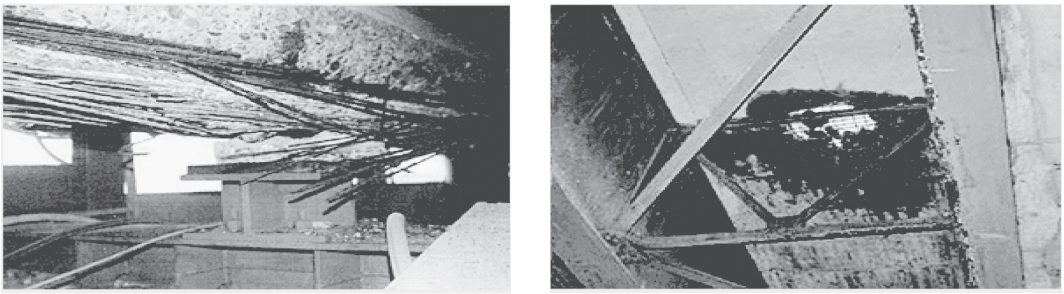



**Figure 2** : Number of bridges and number constructed

Prepared by the STFC based on Reference[6], with some revisions



Fracture of steel materials in main girder of prestressed concrete bridge due to salt damage

Fatigue-related shedding from reinforced concrete slab

**Figure 3** : Examples of bridge damage

From Reference[7]

the period of high economic growth (1955-1973) account for roughly 34 percent of the total, with an average age of 37. With the sudden increases in transportation volume and vehicle weight in recent years, factors such as salt damage and the alkaline aggregate reaction are causing frequent cracking, peeling, and flaking of concrete components, while fatigue of steel components is causing damage from cracking and corrosion. Figure 3 shows examples of damage.

The percentage of Japan's roads that is paved (including surface dressing alone) is currently 97 percent for prefectural and national roads, which were upgraded through the bubble period, and 78.9 percent when municipal roads are included[5].

Pavement includes asphalt pavement and concrete pavement. For general national highways, asphalt pavement currently accounts for 98.9 percent[5]. Asphalt pavement was first applied in Japan in 1878, on the Shohei Bridge in Kanda, Tokyo. Japan's first pavement for automobile use was laid in 1903, the year the first auto appeared in Tokyo. As pavement ages, cracks, bumps, ruts*3, and so on appear on its surface, decreasing the safety and comfort of those using the road.

Japan's first large-scale road tunnel was the Kuriko Tunnel connecting Yamagata Prefecture and Fukushima Prefecture. It was built in 1980 using an American-made excavator, of which there were only three in the world at the time. Currently, there are 8,784 tunnels in Japan, with a total length of 3,224 km. The former public

**Table 1** : Service life from estimates and examples

| Type | Service life | | |
|---|---|---|---|
| | Ministry of Finance | Cabinet Office | Ministry of Land, Infrastructure and Transport |
| Bridges | 60 | 60 | 60 |
| Pavement | 10 | | 10 |
| Tunnels | 30 | | 60 |
| Water and sewer works | | | 50 |
| Rivers | 30 | 40 | Infinity |
| Dams | 50 | | 80 |
| Erosion controls | 30 | 47 | 67 |
| Beaches | 30 | 30 | 50 |
| Housing | 47 | | 61 (where construction began in 1980 or after) |
| Urban parks | | 24 | 43 |

Prepared by the STFC based on Reference[9]

corporations administer 739 locations (8 percent), the national government 3,342 (38 percent), prefectures 2,346 (27 percent), and municipalities 2,357 (27 percent)[5]. Looking at general national highways (designated sections)*4 and national expressways, about 25 percent of their tunnels were constructed during the period of high economic growth[8].

### (3) Road management under difficult natural, geographical, and transportation conditions

Japan's land area accounts for only 0.25 percent of the world's land area, but about 21 percent of the world's major earthquakes (magnitude 6.0 or greater) occur here and around 7 percent of the world's active volcanoes are concentrated in this small country. Furthermore, Japan is approached by an average of more than 10 typhoons per year, and its average annual rainfall of 1800 mm is more than double the world average of 800 mm. Geographically, about 70 percent of Japan's land area is mountainous, with steep mountain ranges crossing the archipelago, and over 20 percent of the habitable land is soft ground. Furthermore, roughly 60 percent of the country is snowy and cold in winter, so the natural conditions are very harsh for roads. The percentage of heavy vehicle traffic*5 in Japan is higher than in Europe or the USA. Steel bridges on roads with an especially high percentage of heavy vehicle traffic are suffering from damage due to fatigue.

Although Japan's core functions are concentrated in the Tokyo metropolitan area, a looping road network is insufficiently formed, leading to the failure of bypass functions and chronic traffic jams in the city center. When major construction requiring road closures becomes necessary because of road damage, the social impact is significant.

### (4) Service life

The renovation of structures can be divided into physical renovation that addresses their damage and aging and functional renovation that addresses obsolescent functionality. Renovation periods related to physical renovation are set according to the Ministry of Finance's "ordinances on the service lives of depreciable assets" and the service lives designated or estimated by various other government agencies. (See Table 1.) Subsequently, the Ministry of Land, Infrastructure and Transport may, when necessary, further segment a facility depending on its characteristics, and designate a service life based on the state of renovation.

For example, in the National Institute for Land and Infrastructure Management's fact-finding survey of bridges (Figure 4), time from construction to replacement was short at 30-40 years for those built during the shortages of World War II and after. Subsequently, however, specifications and guidelines were revised as measures against earthquake damage and other types of damage, so the lives of newly constructed bridges are gradually becoming longer. It is estimated that those constructed

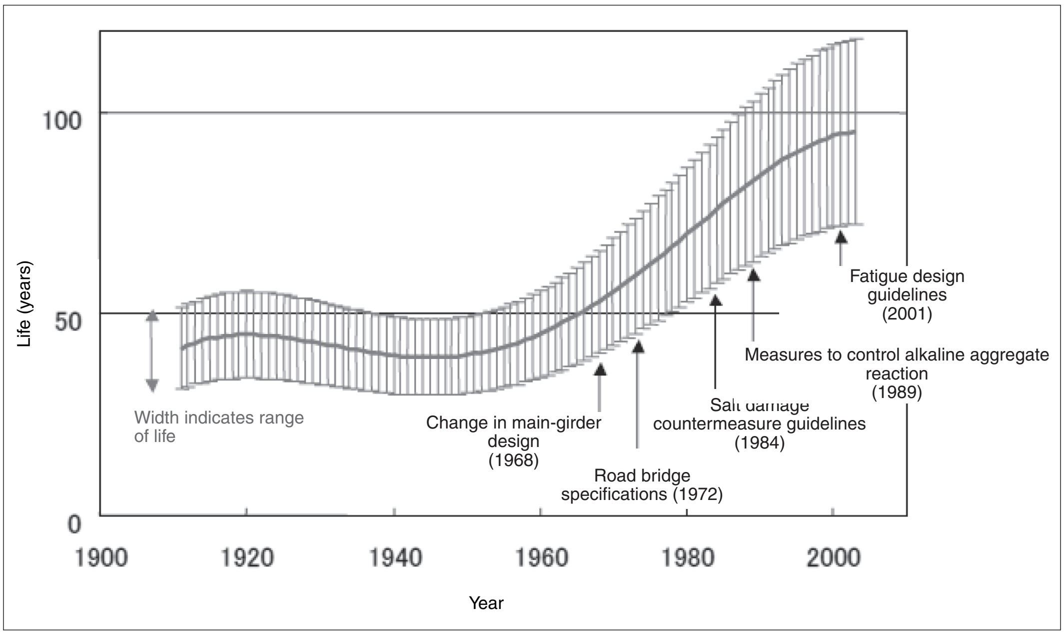



**Figure 4** : Bridge life by year of construction

From Reference[10]

in recent years can have a life expectancy of at least 100 years if properly managed[10]. Because much stock was formed before knowledge of civil engineering technology was sufficient, however, measures for bridges built before the revisions to specifications and guidelines are necessary.

## *3-2 Conditions in foreign countries*

**(1) The USA's response to "decaying social capital"**

In the USA during the 1930s, much of the country's infrastructure was built as part of the New Deal's policies. Beginning in the latter half of the 1960s, accidents occurred due to the failure or aging of public facilities. In 1967, the Silver Bridge connecting West Virginia and Ohio collapsed, killing 46. In 1983, the Mianus River Bridge on a Connecticut interstate highway collapsed, killing 3. During the 1980s, bridges and pavement all over the USA fell into poor condition, and the inability to improve aging road structures led to a situation called the "decaying of America." Public awareness of the crisis in social capital was growing, but lack of management of social capital and poor understanding of the importance of long-term maintenance management prevented the allocation of a sufficient operation and maintenance budget.

Amidst its worsening financial condition, the US government therefore passed the Transportation Assistance Act of 1982, securing funding for priority investment in infrastructure maintenance through an increase in the gasoline tax. Furthermore, the USA expanded its investment in roads with ISTEA (Intermodal Surface Transportation Efficiency Act: 1992-1997) in 1991 and TEA-21 (Transportation Equity Act for the 21st Century: 1998-2003) in 1998. Because of these maintenance and repair initiatives, the number of defective bridges is now decreasing. Still, as of 2004, almost 27 percent of bridges were defective, indicating that once infrastructure is allowed to decay, it is no simple matter in terms of time or money to renovate, repair, and maintain it and ensure safe transportation. There is now strong awareness of the importance of operation and maintenance. Measures are currently being taken under SAFETEA-LU (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users: 2004-2009), which was passed in 2004. Figure 5 depicts the increasing investment in roads in the USA.

**(2) Systematic road facility repair in the UK and Germany**

Learning from the decay that occurred in the USA, the United Kingdom's 1998 "Roads

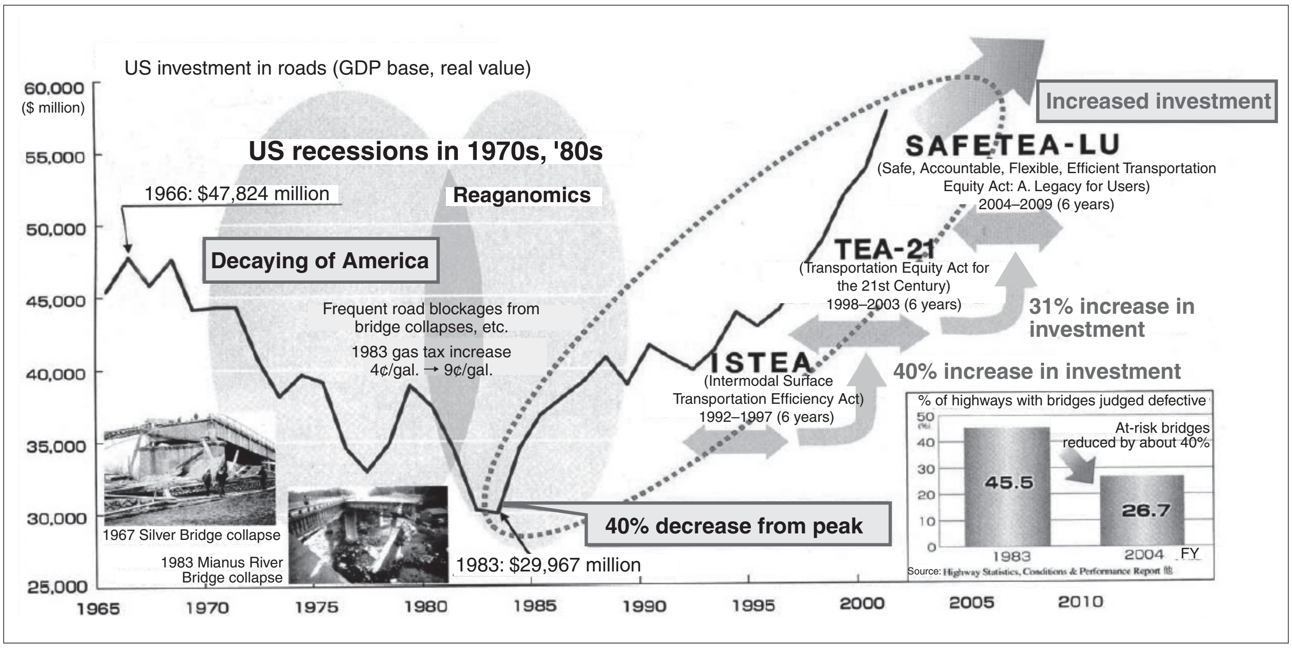



**Figure 5** : US investment in roads

From Reference[11]

White Paper” designated improved operation and maintenance of existing roads as an issue of the highest priority. It clearly indicated the preeminence of operation and maintenance in minimizing the lifetime costs of trunk roads and bridges. Since about 1998, repairs have been carried out through systematic increases in the budget for operation and maintenance. Pavement conditions are improving, and major bridge repair work is proceeding systematically.

In 1933, Germany began building the Autobahn, the world’s first express road network, as part of its economic policy. It has helped support the domestic economy. In the 1990s, however, road damage became apparent. According to a large-scale 1996 fact-finding survey, 5,000 bridges and other structures built during the 1960s and 1970s were at their limits, and a response to larger truck sizes (40 tonnes) was also necessary. Feeling a sense of crisis in response to the Autobahn’s decline, which would have a major impact on the national economy, in 2003 the German federal government promulgated its “Federal Transportation Infrastructure Plan” (2001-2015). It increased investment in maintenance above that in the 1992 10-year plan (by an annual average of 38 percent), promoting the maintenance and renovation of existing infrastructure[12].

## 4 Japan’s need to introduce stock management

**(1) The rapid increase in aging stock**

Intensive construction of the road structures that support the Japanese economy and way of life occurred during the period of high economic growth. There is concern that demand for maintenance and renovation will peak around 2020 through 2030, coinciding with the deterioration of these structures.

Figure 6 shows the number of bridges and tunnels constructed at least 50 years ago. Compared with 2005, the number of bridges at least 50 years old will approximately triple by 2015 and increase roughly eightfold to 64,000 by 2025. As for tunnels that are at least 50 years old, there will be about twice as many in 2015 as in 2005, approximately tripling to 3,600 by 2025. Because the number of aging structures will rapidly increase, higher costs for repair, reinforcement, and renovation will be unavoidable.

**(2) Increased maintenance and renovation costs**

Figure 7 shows the results of two scenarios for estimated expenditures through 2030 on maintenance, operation and renovation of social

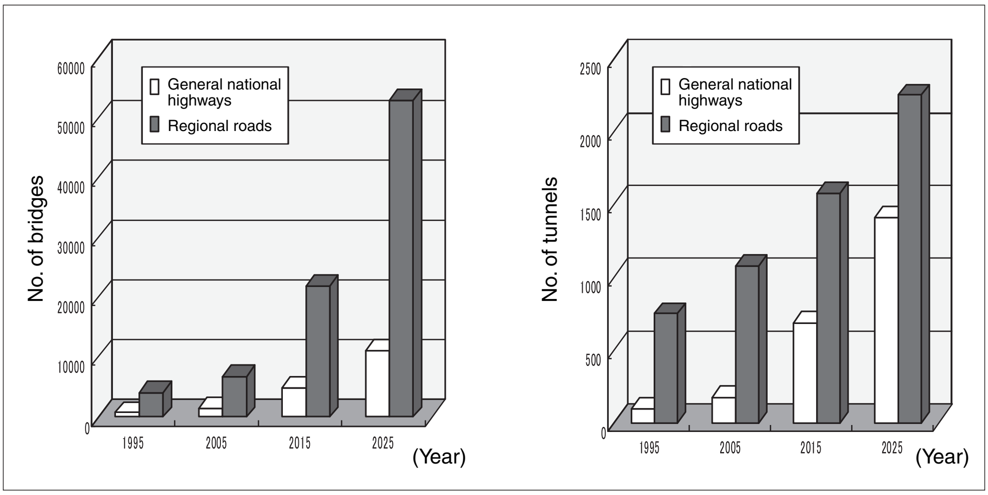



**Figure 6** : Number of bridges and tunnels that are at least 50 years old

Prepared by the STFC based on Reference[7], with some revisions

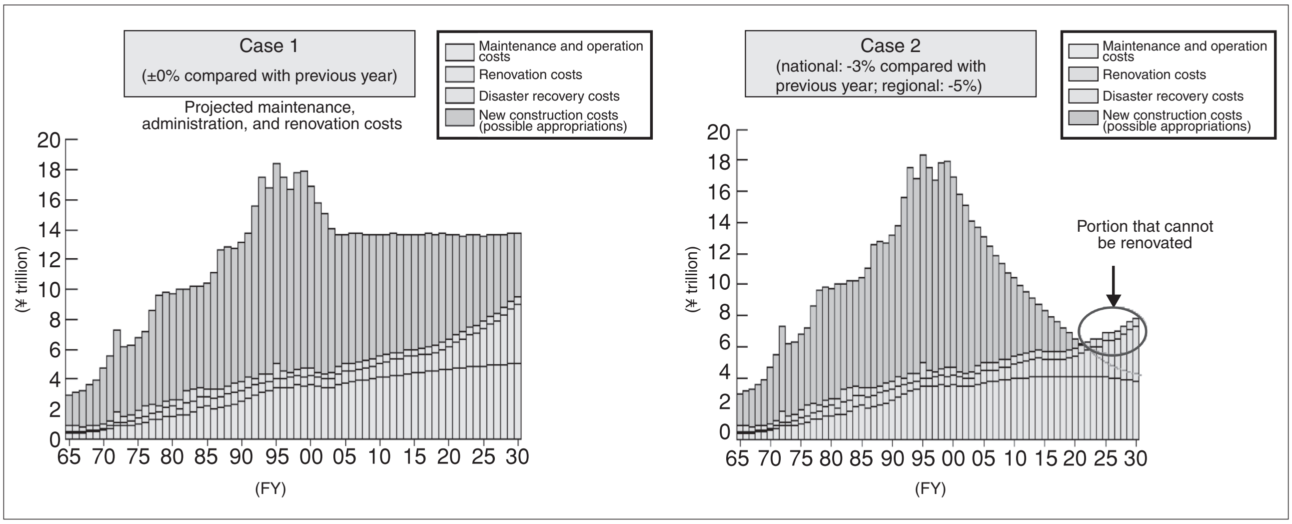



**Figure 7** : Estimated maintenance and administration costs of social capital

From Reference[7]

capital under the jurisdiction of the Ministry of Land, Infrastructure and Transport (roads, ports, airports, public housing, sewers, urban parks, flood control, beaches)[7]. In Case 1 (total available funds are ±0 percent compared with the previous year), maintenance, operation and renovation costs account for 65 percent of available funds in 2030. In Case 2 (total available funds are -3 percent [national] and -2 percent [regional] compared with the previous year), funding becomes insufficient in 2022, and renovation of social capital becomes impossible. According to these estimates, in the future, proper operation and maintenance may become impossible. New construction may become impossible, or it may be impossible to renovate some aging structures.

Therefore, it will be necessary to consider conditions in regional areas that will experience a decline in population and to discriminate among existing road structures in order to appropriately allocate the operation and maintenance funds to be invested in them.

### (3) Increased construction waste

Waste discharged by the construction industry accounts for about 20 percent (75 million tonnes) of all industrial waste in Japan (roughly 412 million tonnes) and approximately 20 percent (7 million tonnes) of industrial waste for final disposal (around 40 million tonnes). On the other hand, about 90 percent of illegally dumped industrial waste (around 410,000 tonnes) is construction waste (354,000)[13].

The recycling rate is climbing slowly year by year, and reached 92 percent in 2002 (for

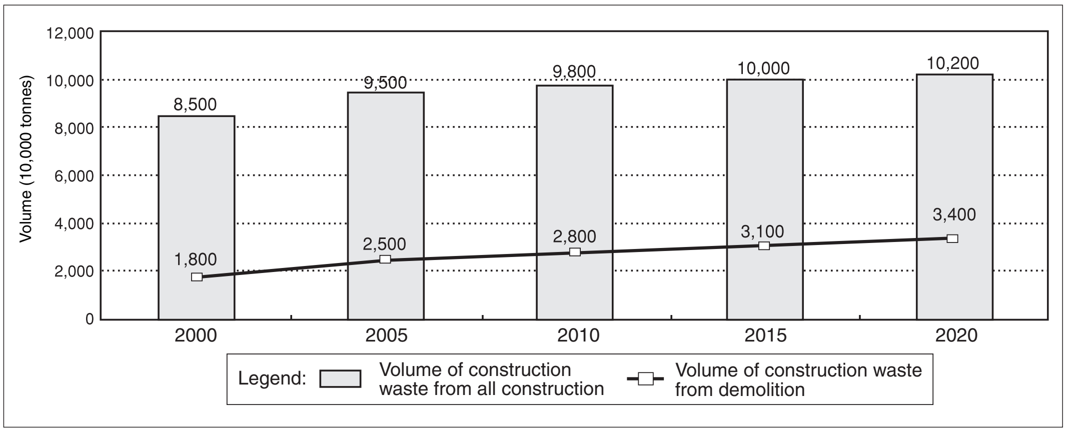



**Figure 8** : Projected future production of construction waste

From Reference[13]

civil engineering and construction combined) according to a Ministry of Land, Infrastructure and Transport survey. However, establishment of new final disposal sites is problematic, so a shortage of residual capacity is occurring[13].

As the number of aging structures increases, the amount of construction waste generated by their demolition is projected to increase as well. (See Figure 8.) From this perspective also, a shift from the conventional scrap-and-build mode to precise maintenance and repair and extended use for maximum life will become necessary.

**(4) Financial constraints**

In the face of concern over lower economic vigor due to factors such as increasing budget deficits, labor shortages accompanying a low birth rate and a larger number of elderly people, and decreasing consumption and investment, coupled with increased expenditures related to social security, there are growing financial constraints on the improvement of Japan's social capital. In fact, public works expenditures have been decreasing since 1999. Furthermore, the shift of funds earmarked for roads to general funds is a problem. Such financial constraints will further increase in the future. It is therefore necessary to ascertain a set of criteria that can also be used in the future and that will permit allocation of the necessary budgets for improvement and maintenance of social capital. The necessity of maintaining and renovating structures must be articulated based on a vision for Japan's future.

In road the management initiatives taken to date, operation and maintenance budgets have been set based on indexes that make a comparison with the previous year's funding and so on. Rather than budgeting from a long-term perspective, repairs are generally made on a stopgap basis when inspections find structures with marked deterioration (corrective maintenance). Because creation of inspection procedures, database construction, and technical development are carried out in isolation, there is an underutilization of management systems that provide a comprehensive overview. In order to adopt stock management methods and minimize lifecycle costs (LCC) from construction to renovation, all processes related to design, construction, operation and maintenance, repair, and renovation must be integrated. Furthermore, preventative maintenance, which intervenes early to carry out minor repairs, thereby preventing major damage from developing later on, must be carried out.

Experience shows that in general, not only can preventative maintenance measures lower total costs compared to corrective maintenance, they can extend structure life and enable standardization of replacement periods[14,15].

## 5 Technology required for stock management

In order to switch from corrective maintenance to preventative maintenance that makes minor repairs before more serious damage becomes apparent, implementation of appropriate operation and maintenance such as that

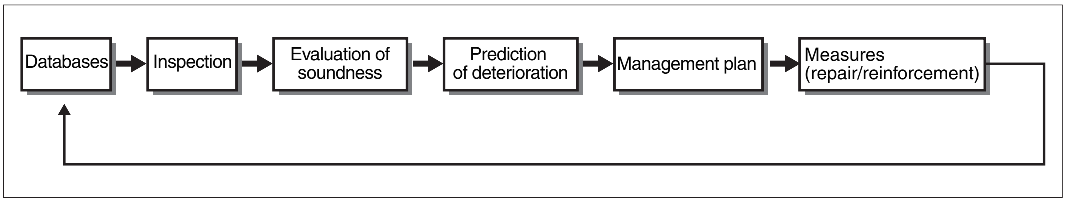



**Figure 9** : The stock management cycle

Prepared by the STFC

illustrated in Figure 9 is necessary. Furthermore, the policies and other knowledge thus obtained must be utilized in the design and construction of new structures in order to improve their longevity.

Below, this article will discuss technologies required at each stage of the cycle.

### *5-1 Deterioration mechanisms and phenomena affecting structures*

The deterioration mechanisms of steel structures are corrosion, fatigue, and delayed fracture. They decrease quality as time in service increases, reducing the life of steel structures. Causes of deterioration in concrete structures commonly used for roads are neutralization, salt damage, frost damage, alkaline aggregate reaction, chemical erosion, and fatigue. Neutralization and salt damage corrode the steel inside concrete when carbon dioxide or chloride ions from the surrounding environment penetrate the material, but they do not cause the concrete itself to deteriorate. On the other hand, the deterioration mechanisms of frost damage, alkaline aggregate reaction, chemical erosion, and fatigue differ, but these phenomena all cause deterioration of the concrete itself. Typical damage caused by these deterioration factors includes cracking, peeling and flaking, free lime, rust fluid, gel exudation, rebar exposure, scaling, and discoloration. They can reduce load-bearing capacity and durability. When different forms of deterioration combine, such as frost damage and salt damage or alkaline aggregate reaction and salt damage, it is difficult to determine the deterioration mechanisms from the concrete's surface.

For details of deterioration mechanisms, see "Structure Maintenance Technology and Risk Based Maintenance (RBM)" in the June 2004 "Science & Technology Trends."

### *5-2 Inspection and diagnosis of structures*

Road structures are exposed to harsh outdoor natural and transportation environments. Implementation of appropriate and efficient operation and maintenance is necessary to enable structures to have longer service lives and to prevent their performance from dropping below desired levels.

The number one goal of inspections is to ascertain the deterioration mechanisms and status of structures, but inspections are also important for data collection for subsequent evaluations of soundness and for deterioration prediction. Damage to structures from combined forms of deterioration is not unusual. In diagnosis, selection of inspection methods with reference to past cases of damage and so on is necessary for effective inspections and analysis of inspection data in order to accurately determine the presence of deterioration and its causes and mechanisms.

Methods for the direct evaluation of the performance of structures and the materials being affected by deterioration include localized destructive testing through core sampling[*6] and load testing of actual structures. Both, however, have the disadvantage of causing damage themselves. In response, non-destructive inspection methods are being rapidly developed and adopted with the goal of more efficient and technically advanced inspections. In addition, research and development into ways of constantly monitoring and measuring important structural and materiel parameters is also progressing. This will allow the performance of structures to be ascertained and facilitate swift action based on those measurements

As in the past, however, the effectiveness of inspection and diagnostic technology is highly dependent on training and experience. Highly experienced inspectors are said to be able to diagnose the deterioration damage mechanisms and status of structures from a visual inspection and photographs with some degree of accuracy. In the future, as aging structures increase all over Japan, there may be a shortage of inspection and diagnostic technicians with such skills.

Table 2 shows the applicability of various inspection methods to concrete structures.

Below, this article will discuss non-destructive inspection and monitoring.

**(1) Non-destructive inspection**

Non-destructive inspection refers to methods that inspect the surfaces and interiors of structures for flaws without damaging them. As noted in Table 3, diagnostic technology for concrete structures commonly used to detect deterioration and flaws include the infrared method, the electromagnetic radar method, and the hammering method. For rebar corrosion, the self-potential method is widely used. Although the degree (amount) of corrosion is an important datum for rebar corrosion, there are currently no tests that can determine this. Development of such a testing method is necessary.

In the case of steel structures, methods for crack diagnosis include ultrasonic inspection, magnetic powder inspection, penetrant inspection, eddy current examination, and radiographic testing. However, in order to use these methods to obtain highly reliable measurements, knowledge of plate combination and welding methods and experience in measurement techniques are necessary. Furthermore, detection is sometimes difficult due to weld line conditions and joint shapes. Research on verification and applicability of measurement results is underway.

The more widespread use of non-destructive inspection can be expected from the perspective of making inspections more efficient and technically advanced. Along with further increases in accuracy and expansion of the range of use, rapid standardization of testing methods is necessary.

Below, this article will discuss “development of a non-destructive diagnosis system for determining the amount of rebar corrosion in rebar concrete” as an example of recent research results.

Inspection methods for rebar corrosion include the self-potential method and the polarization potential method. These are methods for estimating the status and rate of corrosion in rebar, so measurement techniques that can gauge ongoing changes are necessary. The degree (amount) of corrosion is a vital piece of information for the operation and maintenance of structures, but as mentioned above, there are currently no non-destructive inspection methods that can obtain this information. Confirmation requires cutting away concrete to expose internal rebar for visual inspection and other testing to obtain information on deterioration.

Through a joint industry-academia research collaboration, Professor Hideki Oshita of the Faculty of Science and Engineering at Chuo University, Penta-Ocean Construction Co., Ltd., NEC san-ei Instruments, Ltd., and the Research Center of Computational Mechanics, Inc., have developed an efficient “non-destructive diagnostic system for determining the amount of rebar corrosion” that does not compromise the performance of concrete structures[19].

Rust (corrosion) has insulating thermal properties (high specific heat, low thermal conductivity), so when corroded rebar is heated, it conducts less heat to the concrete than sound rebar does. The surface temperature of concrete therefore differs between corroded rebar and sound rebar. (See Figures 10(a), (b), and (c).) Utilizing this characteristic, infrared thermography is used to measure temperature changes, and flaw position imaging software can display the locations and sizes of concrete defects such as floating and cracks. In addition, corrosion degree (amount) diagnosis can be performed by feeding temperature record data back to optimal thermal conduction back-analysis software. From this research, measured rust thickness and analyzed rust thickness in terms of the relationship between rebar corrosion status and covering thickness are as shown in Figure 10(d). The greater the corroded rebar or covering thickness, the greater the value of the analyzed rust thickness tended to be, but the precision caused no problems in operation.

Until now, qualitative judgments were a major

**Table 2** : Applicability of various inspection methods to concrete structures

| Inspection method | Principles Inspection categories, etc. | Deterioration mechanisms | | | | | |
|---|---|---|---|---|---|---|---|
| | | Neutralization | Salt damage | Frost damage | Chemical corrosion | Alkaline aggregate reaction | Fatigue |
| | Deterioration indices | Neutralization depth | Ion concentration | Frost damage depth | Depth of penetration of [corrosive substances][deterioration factors] | Amount of expansion | Degree of accumulated damage |
| | | Amount of steel corrosion | Amount of steel corrosion | Amount of steel corrosion | Neutralization depth | (Cracking) | Steel crack length |
| | | | | | Amount of steel corrosion | | |
| Electrochemical methods | Self-potential method | ◎ | ◎ | ○ | ○ | ○ | |
| | Polarization resistance method | ◎ | ◎ | ○ | ○ | ○ | |
| Stress measurement method | Strain measurement under load | ○ | ○ | ○ | ○ | ○ | ◎ |
| Deformation measurement method | Deformation measurement under load | ○ | ○ | ○ | ○ | ○ | ◎ |
| Visual/photographic inspection | Binoculars, cameras, deformation | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ |
| Hammering test | Impact sound, waveform analysis | ○ | ○ | ◎ | ◎ | ◎ | ○ |
| Rebound hardness method | Test hammer strength | ○ | ○ | ◎ | ◎ | ◎ | ○ |
| Infrared method | Surface infrared imaging | ○ | ○ | ○ | ○ | | ○ |
| Chipping test | Neutralization depth | ◎ | ◎ | | ○ | | |
| | Degree of steel corrosion | ◎ | ◎ | ○ | ○ | ○ | ○ |
| | Tensile strength | ○ | ○ | ○ | ○ | ○ | ○ |
| Core sample testing | Neutralization depth | ◎ | ◎ | | ○ | | |
| | External inspection, crack depth, depth of corrosion, etc. | ◎ | ◎ | ◎ | ◎ | ◎ | ◎ |
| | Compressive strength, tensile strength, coefficient of elasticity | | | ○ | ◎ | ◎ | |
| | Composition analysis | | | ○ | ○ | ○ | |
| | Chloride ion content | ○ | ◎ | ○ | ○ | ○ | |
| | Alkali content analysis | | | | | ◎ | |
| | Aggregate reactivity | | | | | ◎ | |
| | Measurement of expansion | | | | | ◎ | |
| | Pore size distribution | ○ | ○ | ◎ | ◎ | ○ | |
| | Air pocket distribution | | | ◎ | | | |
| | Permeability to air and water | ○ | ○ | ○ | ○ | | |
| Concrete chemical composition | Thermal analysis (TG, DTA) | ◎ | | | ◎ | | |
| | X-ray analysis | ○ | | | ◎ | ○ | |
| | EPMA | | | | ○ | ○ | |
| | Scanning electron microscope observation | | | | ○ | ○ | |
| Methods using elastic waves | Ultrasound, impact elastic waves | ○ | ○ | ◎ | ◎ | ◎ | ○ |
| | AE method | | | | | | ○ |
| Methods using electromagnetic waves (radar methods) | Steel spacing | ◎ | ◎ | ○ | ○ | ○ | ○ |
| | Gaps | | | | ○ | | ○ |
| | Member pressure | | | | ○ | | ○ |
| Methods using electromagnetic waves (infrared method) | Surface peeling | ○ | ○ | ○ | ○ | | ○ |
| Methods using electromagnetic waves (x-ray method) | Steel location and size, gaps, cracks | ◎ | ◎ | ○ | ○ | ○ | ○ |
| Methods using magnetic fields | Steel location and size | ◎ | ◎ | ○ | ○ | ○ | ○ |
| Methods using electricity | Conductivity, water content | ○ | ○ | ○ | ○ | ○ | ○ |
| Load testing (static) | Generation and rigidity of cracks | ○ | ○ | | | ○ | ○ |
| Load testing (vibration) | Natural frequency, vibration mode | ○ | ○ | | | ○ | ○ |

Legend: ◎ : Effective with any degree of deterioration, ○ : Effective depending on degree of deterioration,
No mark: Sometimes useful as reference

From Reference[16]

**Table 3** : Types of non-destructive testing

| Type | Target | Test method | | Summary | Main problem areas |
|---|---|---|---|---|---|
| Concrete structures | Deterioration and defects | Optical methods | | Observation by visual inspection, cameras, CCD cameras, optical fiber, etc. | |
| | | Elastic wave methods | Hammering test method | Discerns the status of internal defects using the sound waves generated by striking the surface of concrete with a hammer | Because it is dependent on human experience and senses, individual differences are significant and it lacks objectivity |
| | | | Ultrasound method | Transmits ultrasound waves from the surface of concrete to the interior, using the propagation time and waveform characteristics of the reflected elastic waves to measure the locations and depths of cracks | • Measurement of slanted cracks is difficult<br>• Measurement is difficult in the presence of rebar |
| | | | AE method | When cracks and fatigue fractures appear and progress, detects the generated elastic waves with AE sensors placed on the surface, measuring the degree of cracking | It is a measurement for progressive forms of damage only |
| | | Electromagnetic wave methods | X-ray method | X-rays are used to take radiographs from the surface of concrete to measure the locations of peeling and cavities | • Expensive and time-consuming compared to other methods<br>• Must have qualifications to use x-rays |
| | | | Electromagnetic radar method | X-rays are used to take radiographs from the surface of concrete to measure the locations of peeling, cavities, and rebar inside concrete | Easily influenced by concrete surface or interior moisture |
| | | | Infrared method | An infrared camera is used to photograph the surface of concrete and measure the locations of peeling and cavities via images showing surface temperature differences | Easily influenced by sunlight conditions on concrete surface |
| | Rebar location and corrosion | Exploratory testing | Radiation method | X-rays and gamma rays are used to take radiographs from the surface of concrete to measure the location of rebar | • Expensive and time-consuming compared to other methods<br>• Must have qualifications to use radiation |
| | | | Electromagnetic induction method | A magnetic field is generated from a sensor with a coil to detect changes in the magnetic fields of magnetic objects such as steel and measure the locations and size of rebar | Can be influenced by bar arrangement (density, wrap) and size, decreasing accuracy |
| | | | Electromagnetic radar method | A structure is exposed to electromagnetic waves, and the reflected data from the differing electromagnetic characteristics of boundary surfaces in the structure are used to measure rebar location and spread | Easily influenced by concrete surface or interior moisture |
| | | | Ultrasound method | Transmits ultrasound waves from the surface of concrete to the interior, using the propagation time and waveform characteristics of the reflected elastic waves to measure the location of rebar | Cannot measure curved areas |
| | | Corrosion testing | Self-potential method | Measures the self potential of rebar to estimate the degree of rebar corrosion | • Measurement accuracy is unclear<br>• Cannot measure degree of corrosion |
| | | | Polarization resistance method | Weak current is passed, and polarization resistance is used to estimate the rate of corrosion | • Measurement is time-consuming |
| Steel structures | Internal defects | Radiographic testing | | X-rays and gamma rays are used to take radiographs from the surface of steel to detect internal defects | • Expensive and time-consuming compared to other methods<br>• Does not provide information on location of damage, its thickness, direction or damage depth<br>• Must have qualifications to use radiation |
| | | Ultrasonic inspection | | Transmits ultrasound waves from the surface of steel to the interior, using the propagation time and waveform characteristics of the reflected elastic waves to measure the locations and depths of cracks | High variability depending on damage location, direction, and size |
| | | AE method | | When cracks and fatigue fractures appear and progress, detects the generated elastic waves with AE sensors placed on the surface, measuring the degree of cracking | It is a measurement for progressive forms of damage only |
| | Surface and surface-vicinity defects | Radiographic testing | | X-rays and gamma rays are used to take radiographs to detect surface and surface-vicinity defects | • Expensive and time-consuming compared to other methods<br>• Does not provide information on location of damage, its thickness, direction or damage depth<br>• Must have qualifications to use radiation |
| | | Ultrasonic inspection | | Transmits ultrasound waves from the surface of steel to the interior, using the propagation time and waveform characteristics of the reflected elastic waves to measure the locations and depths of cracks | Is difficult to distinguish from flaws |
| | | AE method | | When cracks and fatigue fractures appear and progress, detects the generated elastic waves with AE sensors placed on the surface, measuring the degree of cracking | It is a measurement for progressive forms of damage only |
| | | Eddy current examination | | Detects as electric signals changes in eddy currents generated by coils that pass alternating current, thereby ascertaining the extent of damaged areas through the signals' amplitudes and phases | It is difficult to accurately determine the type, shape, and dimensions of damage |
| | | Infrared method | | An infrared camera is used to photograph the surface of steel and measure the locations of peeling and cavities via images showing surface temperature differences | Easily influenced by sunlight conditions on steel surface |
| | | Magnetic powder inspection | | When magnetic objects such as steel are exposed to a magnetic field, any damage that exists will disrupt the magnetic field in its vicinity, and scattered magnetic powder will adhere to it, enabling the detection of damage | Applicable only to magnetic objects |
| | | Penetrant inspection | | Colored or luminescent penetrants that make damage easy to see are soaked into steel surfaces and then sucked out to enlarge damage to facilitate detection | Requires removal of surface paint and oil within damaged areas |

Prepared by the STFC with reference to References[17,18]

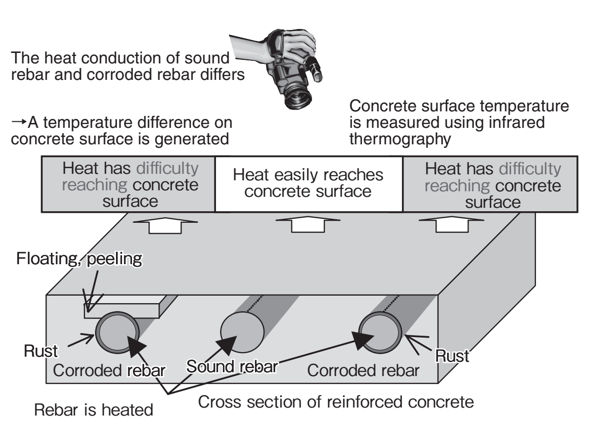



**Figure 10(a)** : Non-destructive diagnostic method using rebar heating

From Reference[20]

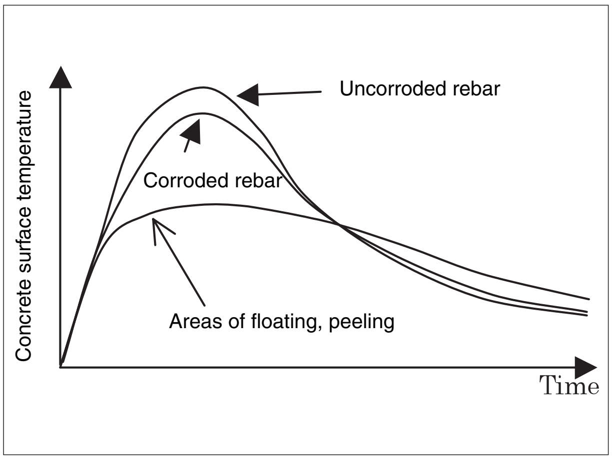



**Figure 10(b)** : Surface temperature of concrete after rebar heating

From Reference[20]

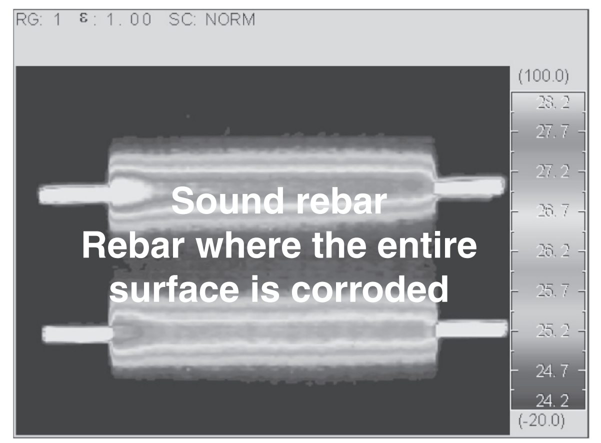



**Figure 10(c)** : Heat image 300 seconds after heating stops (see color image on cover)

Provided by: Professor Hideki Oshita of Chuo University

| Degree of rebar corrosion | Covering (mm) | Measured rust thickness (mm) | Analysis result (mm) |
|---|---|---|---|
| Rebar where the entire surface is corroded | 30 | 0.043 | 0.039 |
| | 50 | 0.047 | 0.042 |
| | 70 | 0.046 | 0.057 |
| Rebar showing partial corrosion | 30 | 0.463 | 0.526 |

**Figure 10(d)** : Results of analysis of corrosion amounts using optimum control theory

Prepared by the STFC based on Reference[20]

part of flaw location evaluation from thermal imaging, so only experts were able to perform it. The newly developed image processing system, however, automatically derives defect location and size, so even non-experts can perform diagnosis.

Initially, the rebar heating method in this R&D involved breaking part of the concrete structure in order to attach electrical wires to rebar for heating. Because this was disadvantageous in terms of damage to structures and efficiency, the method was improved so that electromagnetic induction coils on structure surfaces send an induction current to the rebar, enabling uniform rebar heating. Currently, research to develop a portable electromagnetic induction heater enabling easier inspection is progressing. Furthermore, this research has targeted only horizontal reinforcement, but because actual structures combine horizontal and vertical reinforcement, concrete surface temperature is highest at points where they join. Research on image processing methods to evaluate the characteristics of deterioration at these points is also making headway.

In addition, a portable x-ray fluorescence spectrometer that can be used on-site has recently been developed. For more details, see “Measuring Chloride Ions inside Concrete with Portable Equipment” under “Topics” in the March 2007 “Science & Technology Trends.”

### (2) Monitoring technology

Monitoring objectively ascertains, observes, and evaluates deterioration and disturbance in structures. It is necessary to constantly monitor whether a structure is retaining its required performance or if significant damage is occurring and to reflect the results in policy.

Monitoring methods comprise placing sensors on structures and connecting them by optical cables and so on to distant monitor screens for

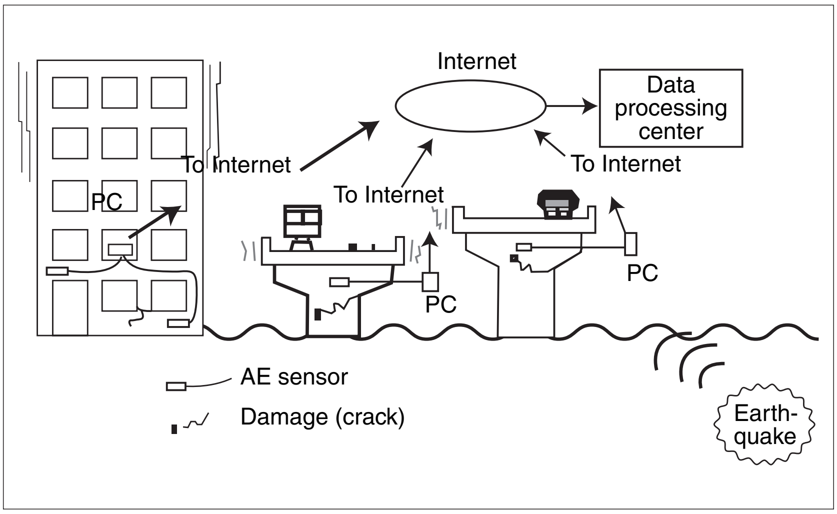



**Figure 11** : AE sensor concept

Prepared by the STFC based on Reference[21], with some revisions

constant observation or periodically moving instruments for on-site connection to structure sensors.

Monitoring can observe a structure's macro behavior, for example, detecting abnormalities following an earthquake or other disaster, or it can progressively observe cracking or corrosion in a structure's components. Much recent research has focused on the observation of entire structures. This is largely because of the development of AE sensors*7 and optical fiber sensors. For example, when an earthquake occurs, AE sensors and so on can be used to provide information from on-site to allow damage evaluation. Inspectors can be dispatched on a priority basis in accordance with the evaluation provided by this monitoring to facilitate an early recovery response. Its expanded adoption, however, depends on lowering the cost. Figure 11 provides an overview of AE sensors.

## 5-3 Evaluation of soundness

Soundness indicates the degree to which a structure satisfies its functional and performance requirements. Currently, there is no generalized method of computing it. The subject of evaluation may, like bridges, be composed of various components with different functions, or, like pavement, be made of an almost uniform material. Because it may be difficult to express this with a single form of soundness evaluation, evaluation units for each structure must be determined. In the case of bridge management, methods such as setting inspection soundness coefficients for each component and weighted coefficients between components to obtain weighted averages and derive the soundness of individual bridges are being proposed. This article will discuss the Ministry of Land, Infrastructure and Transport's method for evaluating salt damage in Chapter 6 below.

## 5-4 Deterioration prediction

Based on statistical analysis of inspection results, theoretical formulas, and so on, prediction of deterioration expresses the performance of a structure on a temporal axis to forecast the type of damage that will occur to the structure over time. Evaluation and judgment of durability at a given stage is important for operation and maintenance planning of repair and reinforcement measures. The practicality and effectiveness of operation and maintenance planning depends on the quality of inspection data and the accuracy of deterioration prediction.

Deterioration prediction methods for individual deterioration causes that are the subjects of forecasts of future soundness include lifespan-setting methods, methods that use theoretical deterioration prediction formulas, methods that statistically analyze inspection results, and methods using transition probability*8. Table 4 shows overviews, characteristics, and the issues associated with each method.

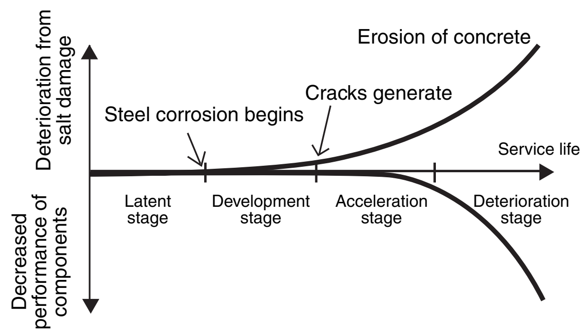
Regarding theoretical deterioration prediction formulas, the Japan Society of

**Table 4** : Overview of methods for predicting deterioration and their characteristics and issues

| Method | Overview | Characteristics and issues |
|---|---|---|
| Method that sets life span | The method sets a life span for each bridge component, creating prediction lines or curves with “Sound” at time of construction or repair and “Needs repair” at the end of the life span | • Repair dates for the components of individual bridges can be set with certainty<br>• The criteria for setting life spans are an issue<br>• Determining the rate of deterioration during the life span is an issue |
| Method using theoretical deterioration prediction formulas | Uses theoretical prediction formulas according to the deterioration mechanism (e.g., prediction of chloride ion diffusion, neutralization progress, and RC slab fatigue as set out in the Japan Society of Civil Engineers’ Standard Specifications for Concrete Structures “Maintenance”) | • Repair dates for the components of individual bridges can be set with certainty<br>• The theoretical bases of prediction formulas are clear<br>• The deterioration causes to which theoretical prediction formulas can be applied are currently limited<br>• Survey data are necessary for deterioration prediction |
| Method using statistical analysis of inspection results | The method uses inspection results to statistically analyze the relationship between age and soundness and create prediction lines or curves<br>Prediction formulas are set for categories such as component, deterioration cause, environmental condition, year of completion, etc. | • Repair dates for the components of individual bridges can be set with certainty<br>• Because it is based on analysis of inspection results, the basis for setting is clear<br>• Prediction accuracy can be improved by sorting inspection data according to deterioration cause, environmental conditions for various bridges, amount of traffic, etc.<br>• Prediction accuracy depends on the quality of inspection data |
| Method using transition probability | Using transition probabilities between ranks of soundness, the method calculates the probability of transitions between ranks by the Markov process*9<br>Transition probability is calculated using years of inspection results for components and deterioration causes | • Repair dates and costs for the components of individual bridges cannot be predicted<br>• It is difficult to reflect in short-term planning for individual bridges<br>• Because transition probabilities are set according to inspection results, their basis is clear<br>• Effective for management of multiple bridges |

Note: Here “life span” is used to refer to the period from construction or repair until “needs repair”

Prepared by the STFC based on Reference[22], with some revisions




Prediction formula for chloride ion diffusion

$$C(x,t) = C0\left[1 - erf\frac{x}{2\sqrt{D \cdot t}}\right] + C(x,0)$$

C(x, t): chloride ion concentration (kg/m$^3$) at depth x (cm), time t (years)
C0: chloride ion concentration (kg/m$^3$) at surface
D: apparent chloride ion diffusion coefficient (cm$^3$ • year) at surface
erf : error coefficient
C(x, 0): initial chloride ion content (kg/m$^3$)

**Figure 12** : The process of deterioration through salt damage

From Reference[16]

Civil Engineers’ Standard Specifications for Concrete Structures “Maintenance” proposes a performance verification formula for the deterioration mechanisms of neutralization, salt damage, and fatigue of reinforced concrete floor slabs. Inputting the specifications and environmental conditions of concrete materials and structures enables the period when deterioration phenomena will occur, the progress of deterioration, and so on to be estimated to a certain degree. At this time, however, it is difficult to perform deterioration prediction with a sufficiently reliable degree of accuracy for frost damage, chemical erosion, alkaline aggregate reaction, or combined deterioration. Furthermore, improved deterioration prediction accuracy following repair reinforcement is necessary. Progress in this research is hoped for.

Figure 12 shows the process of deterioration due to salt damage. Deterioration proceeds through the latent, development, acceleration, and deterioration stages over the structure’s life.

Figure 12 shows a theoretical formula for predicting the diffusion of chloride ions

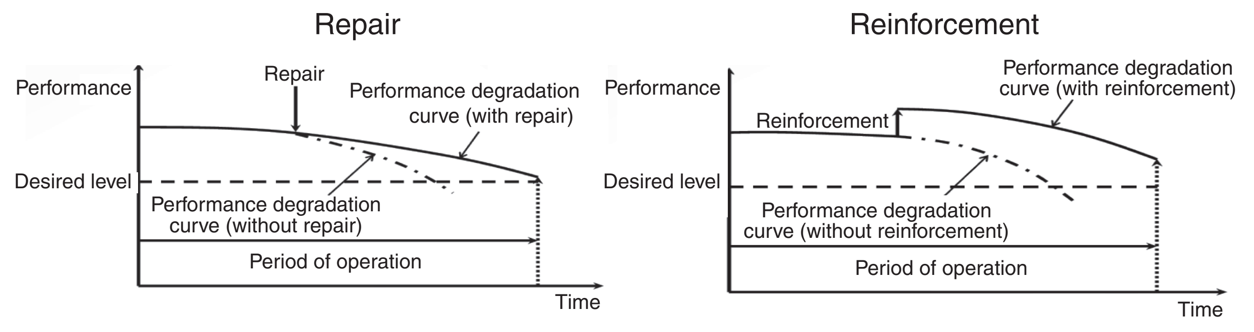



**Figure 13** : Conceptual diagram of repair/reinforcement

Prepared by the STFC

from the Japan Society of Civil Engineers' Standard Specifications for Concrete Structures "Maintenance" as an example of a prediction formula.

### *5-5 Repair and reinforcement*

Repair and reinforcement measures require comprehensive evaluation not only of the actual and desired performance of structures, but also of economy and the progress of deterioration after implementation. Causes of deterioration and disturbance must be clarified, measures examined, optimal repair and reinforcement methods selected, and structure performance maintained and improved. However, in order to reduce operation and maintenance costs, minor repairs should be performed using preventative maintenance methods before significant damage becomes apparent in order to minimize life-cycle costs. In order to achieve this, progress on inspection and diagnostic technology and deterioration mechanisms and improvement in the accuracy of deterioration prediction that reflects repair results are necessary.

Generally, repairs are a means to extend the lives of structures and components or to restore or improve their durability. Reinforcement is generally a means to restore or improve their mechanical properties such as load-bearing capacity or rigidity. Figure 13 is a conceptual diagram of repair and reinforcement.

There are many kinds of repair and reinforcement technologies. (see Table 5.) Cases where the wrong construction method was selected and the prescribed results not obtained are sometimes seen. They require re-repair or re-reinforcement during their service life. Clarification of the performance, results, and applicability of different methods and establishment of a system for selecting optimal repair and reinforcement methods to satisfy performance requirements in response to different deterioration causes are necessary.

In recent years, R&D on concrete materials that repair themselves when cracks appear in concrete structures has been underway. If the research objectives were to be realized, this would lengthen the lives of structures and make maintenance easier. Further development is expected.

## 6 Development of bridge management systems

Bridge management systems (BMS) are being developed as tools to support the systematic management of bridges. The following is an overview.

A BMS is a simulation system that inputs information such as a bridge's specification data, inspection data, repair record data, and environmental conditions. A soundness prediction program prepared in advance forecasts present soundness and future deterioration. When multiple conditions such as various repairs or renovation plans are added, a simulation of costs and the bridge's soundness under various conditions is run. Comparison with the available budget enables the creation of an optimal bridge operation and maintenance plan[24].

As discussed in Section 3-2, around 1970, the USA began to experience service problems with bridges in various areas. It has thus embarked upon the creation of inspection and certification

**Table 5** : Construction methods for types of repair and reinforcement

| Structure type | Repair / reinforce-ment | Purpose of measure, etc. | Method | Overview |
|---|---|---|---|---|
| Concrete structures | Repair | Creation of barrier to deterioration causes | Crack covering method | A film (polymer cement paste, cement filler, elastic waterproofing film, etc.) is formed over minute cracks (generally no more than 0.2 mm) to improve waterproofing and durability. Cracks only or entire surfaces may be covered. |
| | | | Crack injection method | Organic or cement-based materials are injected into cracks to prevent air, water, chloride ions, and other causes of corrosion from penetrating concrete, increasing waterproofing and durability. |
| | | | Filling method | Concrete is cut along relatively large cracks (0.5 mm or larger), and repair materials (sealant, flexible epoxy resin, or polymer cement mortar) is injected into the cut area. |
| | | | Coating method | The surface of a structure is covered with a resin-based or polymer cement-based material to create a barrier to deterioration factors, inhibiting the progress of deterioration. This method is used when a structure's durability improvement and aesthetics need to be considered. |
| | | Removal of deterioration causes | Section repair method | The method aims to repair sections when structures have lost sections due to deterioration or concrete containing deterioration factors such as neutralization, chloride ions, etc., have been removed. |
| | | Control of the rate of deterioration | Electric protection method | Anode material is placed on the surface of concrete, supplying a direct current (about 10–30 V/m2) through the concrete to the rebar, changing its polarity to negative in order to prevent corrosion. |
| | | Removal of deterioration causes | Desalinization method | Employing the electric protection method, a large direct current (1 A/m2) is passed to the steel within concrete, which causes desalinization through electrophoresis of chloride ions inside the concrete extending to its exterior surface. |
| | | Control of the rate of deterioration | Realkalization method | Like the desalination method, a large direct current (1 A/m2) is passed to the steel within concrete, and an alkaline liquid is infiltrated into the concrete towards the rebar, making the concrete alkaline. |
| | | Prevention of impact on third parties | Peeling prevention method | A fiber sheet is set in place to prevent peeling of covered concrete, mortar, etc. |
| | Reinforcement | Replacement of concrete components | Replacement laying method | Strengthening is accomplished by replacing concrete components with marked deterioration and degraded load-bearing capacity that are hard to repair with new concrete components. |
| | | Increase of concrete sections | Thickening method | Rebar and other reinforcing materials are set in place mainly to thicken floor slabs, on the underside of floor slabs or main girders, aiming to improve performance by integrating concrete or mortar. |
| | | | Lining method | Rebar, etc., is placed all around main girder components that have lost load-bearing capacity, aiming to improve performance by integration with concrete. |
| | | Addition of reinforcing materials | Adhesive method | Steel plates or carbon fiber is affixed to floor slabs and girder components that have lost load-bearing capacity, aiming to improve performance by integration with existing components. |
| | | | Lining method | Steel plates or carbon fiber are connected to floor slabs and girder components that have lost load-bearing capacity, aiming to improve performance by integration with existing components using concrete components or adhesives. |
| | | Introduction of prestressing | External cable method | Tendons (rebar or continuous fiber reinforcement) are set in place as a prestressing measure, to improve component stress conditions and increase flexural capacity and shear capacity. |
| | | Removal of expansion/ contraction equipment | Continuous method | PC steel bars and connecting plates are used to connect the main girders of existing simple girders, and the expansion gaps between girders are filled with mortar, etc., so that it connects to the road surface without an expansion apparatus by restricting the relative offset of the girder ends. |
| Steel structures | Repair | Corrosion prevention | Recoating (all or part) method | Corrosion that would have a major impact on the durability of a structure is prevented by coating. |
| | | Crack repair | Weld repair method | This method uses arc air gouging to remove cracked areas from welds and then makes repairs by re-welding. |
| | | Crack/corrosion repair | Complete component replacement | When there is marked damage to a section because of corrosion of secondary components, this method replaces the damaged components in their entirety. |
| | | | Lath repair method | This method adds steel plates to areas where there are section damaged by corrosion or where cracks have generated in order to prevent degradation of current performance or the generation of more cracks. |
| | Reinforcement | Ensuring desired performance | Structural improvement | When desired performance is deficient in terms of load-bearing capacity and durability, this method improves the details that are a weakness in fatigue damage by increasing main girders and vertical girders, connecting simple girders, and shifting supports. |
| | | | Component thickening | This method aims to improve performance mainly by increasing the thickness of floor slabs and attaching steel plates and carbon fiber sheeting to their undersides. |
| | | | Component addition | This method aims to raise load-bearing capacity by reinforcing main girders with cover plates or external cables. |

Prepared by the STFC based on References[18,23] systems, database construction, and development of analysis systems for operation and maintenance and budget management. A typical American BMS is the PONTIS system developed by the Federal Highway Administration (FHWA) in 1991 on the Windows platform and upgraded several times since. The FHWA provides it to state governments, districts, counties, cities, and toll road operators. The system has also been implemented in Hungary and Kuwait. In Europe, there are systems such as the UK's SSBP (Bridge Stabilization Program) and Denmark's DANBRO (Comprehensive Bridge Management System).

In Japan too, the Ministry of Land, Infrastructure and Transport, the former road public corporations, local governments, and so on are carrying out research to effectively utilize their limited budgets for operation, maintenance, and renovation of their large stocks. Here this article will give an overview[6] of BMS research and development by the National Institute for Land and Infrastructure Management of the Ministry of Land, Infrastructure and Transport.

As depicted in Figure 14, in the actual management of road bridges, it is difficult to accurately forecast the future for bridges under varied conditions just from the statistical processing of objective data. Drafting of management plans is highly dependent on qualitative and experienced evaluation based on the knowledge of experts. However, adoption of a BMS enables more rational planning through the insertion of information from data-based forecasting and quantitative and objective evaluation into the management plan drafting process.

First, evaluation of current damage status is performed to forecast soundness. For items for which soundness forecasting is practical, the results of regular inspections are utilized, and depending of the status of damage, soundness is determined and evaluated according to I through V of "1. Evaluation of soundness" is shown in Figure 15. The Chart shows the example of salt damage to concrete components. This is an example of the use of a method that determines the five levels of soundness used in the BMS utilizing a theoretical formula involving the deterioration process designated by the Japan Society of Civil Engineers according to such factors as total chloride ion volume and steel volume loss rate.

Deterioration prediction should use the inspection data needed for future forecasts and deterioration prediction methods in accordance with the types of deterioration being targeted. At this point, however, the Ministry of Land, Infrastructure and Transport's draft guidelines

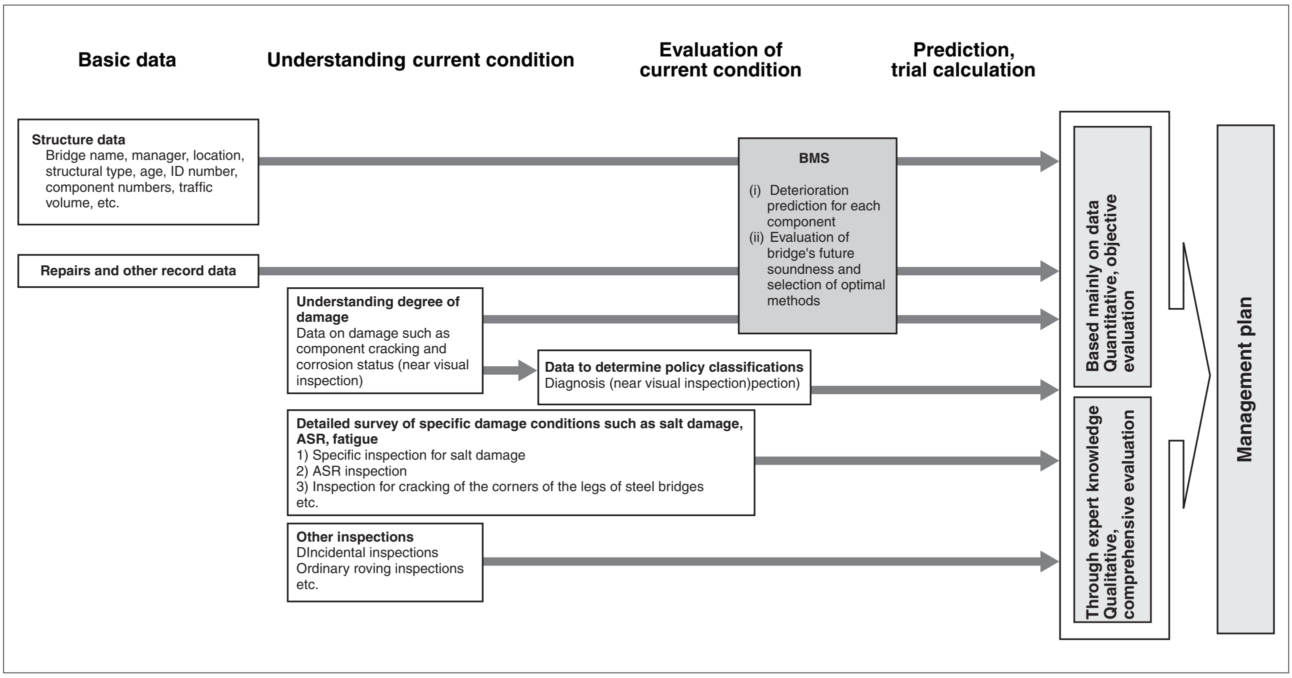



**Figure 14** : The position of BMS in management planning

From Reference[6]

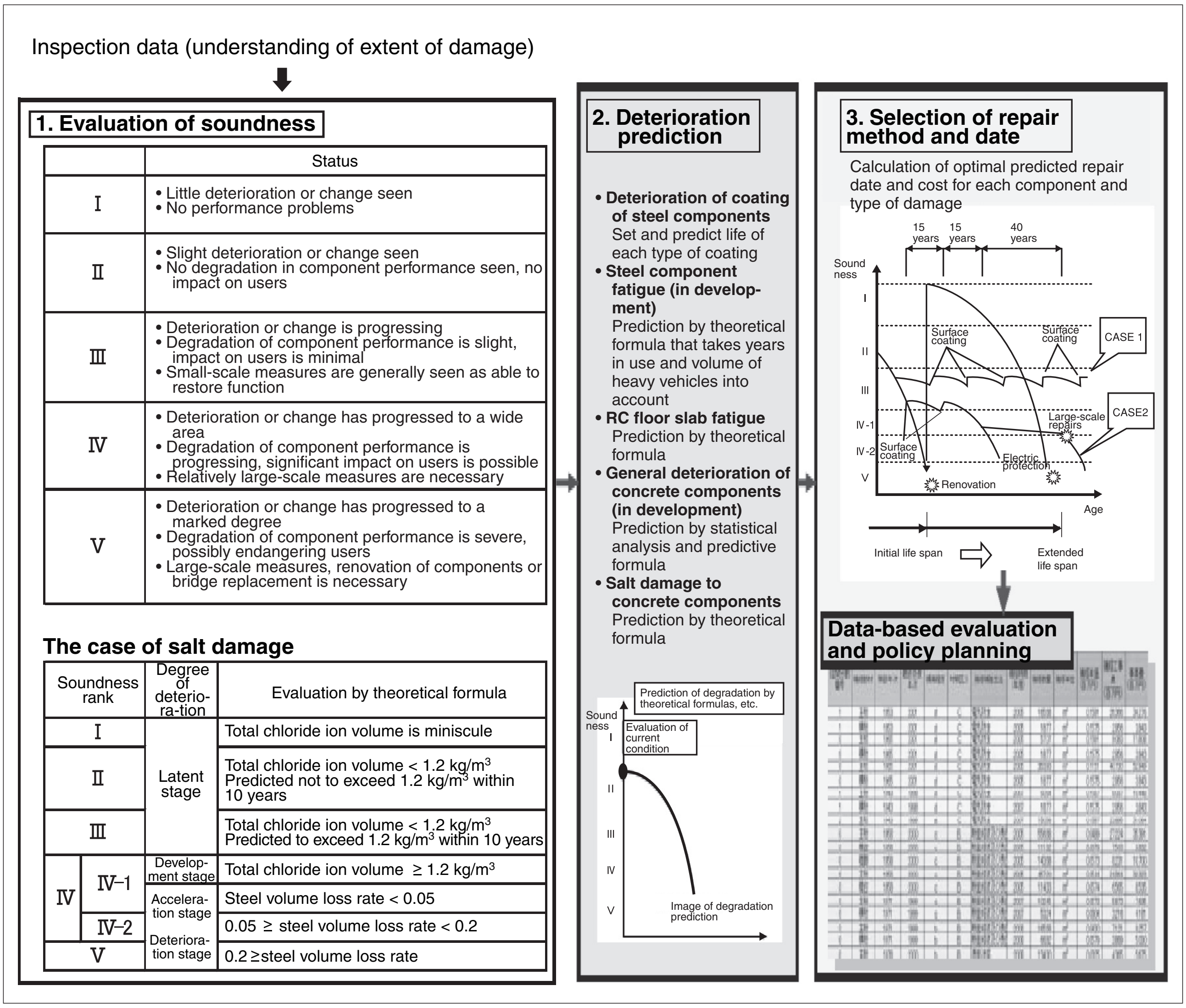



**Figure 15** : Image of BMS calculations

From Reference[6]

for regular bridge inspection are still skimpy. Because there are few deterioration causes, such as salt damage and fatigue, whose inspection results can be specified, at this time there are issues with accuracy and individual application. However, the present method uses a deterioration prediction formula based on a theoretical formula. Currently, actual deterioration prediction with the BMS is limited to coating deterioration of steel components, fatigue of steel components and reinforced concrete floor slabs, and salt damage to concrete components. Within the BMS, however, using a bridge's current status evaluation and future forecasts to calculate recommended repair dates and costs for each component and type of damage can provide information useful in planning countermeasures.

Relevant organizations in Japan are actively pursuing research and development on BMS. Early development, adoption, and operation of highly accurate systems are necessary.

## 7 Conclusion

In order to operate and maintain steadily aging road structures in the face of a low birth rate, a larger number of elderly people, and difficult financial conditions, the "corrective maintenance" utilized to date must be shifted to "preventative maintenance." In order to standardize replacement periods, shrink life-cycle costs, and reduce risk, a systematic response to the following points is necessary.

**(1) Full-fledged adoption of stock management methods**

As the replacement period approaches for a vast number of road structures from about 2020 through 2030, maintenance methods should be shifted from “corrective maintenance” to “preventative maintenance” in order to standardize renovation. It is necessary to carry out minor repairs before serious damage becomes evident, increasing longevity and reducing life-cycle costs. In order to accomplish this, rather than relying on the piecemeal performance of the inspection, evaluation, deterioration prediction, and so on of structures that has been carried out to date, stock management systems integrating these elements should be constructed. Such systems are necessary to ensure the long life and use of existing stock.

**(2) Technical development**

In order to perform efficient road management, elucidation of the mechanisms of deterioration causes needs to be promoted. In addition, further improvement of deterioration prediction technology, non-destructive inspection technology, monitoring technology, development of effective and economical repair and reinforcement methods, increased structure longevity, inspection technology, and renovation technology that minimizes impacts on transportation and the environment when replacements are made are necessary. In this research and development, instead of individual institutions pursuing research independently, industry, government, and academia should collaborate on R&D projects. They should establish a roadmap to promote research and development.

**(3) Development of human resources with advanced measurement and judgment skills**

In order to properly maintain and manage aging structures as their number increases, more technicians who can apply a high level of knowledge, experience, and appropriate technical judgment using stock management methods at all stages, from design through construction, inspection, and operation and maintenance, will be necessary. Because human resources development requires long periods of time, systematic fostering of these personnel is required.

Because the accumulation of expert knowledge and on-site experience is necessary in this human resources development, in-house technicians and consulting technicians should be upgraded through on-the-job training and other hands-on training. Establishment of a certification system in accordance with levels of technical ability is needed. For example, in higher education in the civil engineering and construction field, there is still little training available in “operation and maintenance engineering,” but it will become necessary in the future. Furthermore, establishment of an “operation and maintenance sector” for professional engineers and registered civil engineering consulting managers (RCCMs) would ensure incentives and the acquisition of advanced technical ability. In addition, preparation of an environment that will attract outstanding technicians by outsourcing inspections and reviewing of expenditures is also necessary.

**(4) Technical and financial support for local governments**

The road network, from national expressways to municipal roads, forms and functions as an integrated unit. Improving the management of regional roads, which account for about 97 percent of all roads, is a key point in raising the overall level. In many cases, however, financial constraints and a shortage of technicians in local public agencies mean that operation and maintenance are insufficient. Promotion of the implementation of the Private Finance Initiative (PFI), which involves the national government in the utilization of private-sector funds, and creation of measures for the support of local governments in financial difficulty will also become necessary. Furthermore, the national government, universities, and independent administrative agencies, foundations, and incorporated associations involved with social infrastructure will need to take the initiative in providing technical support to local governments.

**Acknowledgments**

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**Glossary**

1 Former public corporations
Refers to the Japan Highway Public Corporation, the Metropolitan Expressway Public Corporation, the Hanshin Expressway Public Corporation, and the Honshu-Shikoku Bridge Authority.

2 Reinforced concrete bridges and prestressed concrete bridges
Concrete is a powerful material in terms of compression, but is only about one-tenth as strong in terms of its resistance to tensile stresses. To compensate for this weakness, reinforced concrete bridges combine rebar on the tension side, while prestressed concrete bridges use high-tension prestressed concrete steel material similar to piano wire to impart compressive strength to the concrete in advance. This gives the concrete in these bridges the ability to withstand tensile stresses.

3 Ruts
Indentations that form where tires pass over paved surfaces due to the weight of vehicles, friction on asphalt, and flowage.

4 General national highways (designated section)
Refers to sections of general national highways designated by government order ("government order setting designated sections of general national roads") for maintenance, repair, disaster recovery, and other management by the Minister of Land, Infrastructure and Transport (the Road Bureau, and in Hokkaido, the Hokkaido Regional Development Bureau, of the Ministry of Land, Infrastructure and Transport; in Okinawa, the Okinawa General Bureau of the Cabinet Office) under Article 13 Section 1 of the Road Law.

5 Percentage of heavy vehicle traffic
The ratio of heavy vehicles (buses, ordinary freight vehicles) to all vehicle traffic, expressed as a percentage.

6 Core sampling
A hole is opened with a core-boring machine or other device, and the extracted cylindrical sample is used to ascertain the structure's performance and materials degradation.

7 AE sensor
When cracking occurs in a structure due to deterioration, earthquakes, and so on, the cracks generate ultrasound waves (AE waves), which spread throughout the concrete structure. An AE (acoustic emission) sensor properly located on a structure converts AE waves into an AE signal and sends it to monitoring equipment.

8 Transition probability
Expresses the probability that an object under condition x' at time t' will transition to condition x at time t.

9 Markov process
A probability process with the characteristic that future behavior depends only on the current value, and past behavior is irrelevant.

**Abbreviations**

*ISTEA:* Intermodal Surface Transportation Efficiency Act

*TEA-21:* Transportation Equity Act for the 21st Century

*SAFETEA-LU:* Safe, Accountable, Flexible, Efficient Transportation Equity Act:

A. Legacy for Users

*BMS:* Bridge Management System

*FHWA:* Federal Highway Administration

*PONTIS:* The French word for "bridge," a bridge management system

*RCCM:* Registered Civil Engineering Consulting Manager

*PFI:* Private Finance Initiative

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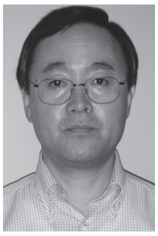

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6

# Report on the AAAS Forum on Science and Technology Policy

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## 1 Introduction

A two-day Forum on Science and Technology Policy was held by the American Association for the Advancement of Science (AAAS)*1 on May 3 and 4, 2007, in Washington, DC. This policy forum has been held every spring since 1976. This year's was the 32nd[1]. (The name was changed from "colloquium" to "forum" beginning in 2004.)

This policy forum differs from the large AAAS Annual Meeting where symposiums on a variety of themes are held. The number of sessions and themes are limited, and the forum takes up issues facing the US science and technology community, such as trends and areas of policy emphasis in Congressional debate on the science and technology budget and recent changes in status. It provides an important opportunity for scientists, relevant government officials etc. to meet together and discuss these issues with shared awareness.

This year, over 400 people participated, including government officials such as John H. Marburger, III, Science Advisor to the President (and Director, White House Office of Science and Technology Policy), who attended for the sixth straight year; members of the legislative branch including Bart Gordon, Member, US House of Representatives (Democrat, Tennessee), chairman, House Committee on Science and Technology; university educators and researchers; researchers and analysts from relevant think tanks; members of relevant academic societies; and people involved with science and technology policy in other countries. The themes for this year were as follows[2].

**Plenary Sessions**

- Budgetary and Policy Context for R&D in FY 2008
- Pharmaceutical and Biotechnology R&D
- Sequestered Science

**Concurrent sessions**

- States' Expanding Roles in Science and Technology
- Building Science, Technology, and Innovation Capacity in Developing Nations
- Surveillance, Privacy, and the Roles of Science and Technology

This article will report on the main points discussed at the policy forum.

## 2 AAAS analysis of Federal budget proposals for R&D in FY 2008

The Federal budget request released in the President's FY 2008 budget message on February 5, 2007, was $2.902 trillion, with a Federal R&D budget of $143 billion. This is a 1.3 percent increase from FY 2007[3]. Of this, 58 percent (around $82.9 billion) is for defense-related R&D, with the remaining 42 percent (about $60 billion) going to non-defense R&D. The Department of Defense (DoD) R&D budget accounts for about 95 percent of the defense-related R&D budget. The total represents a 1.0 percent increase from the previous fiscal year's budget of $78.996 billion. The budget for weapons development in particular increased 5.5 percent, to $68.1 billion. On the other hand, the science and technology budget including DoD basic and applied research is on a downward trend, falling 20.1 percent to $10.9 billion. (However, the science and technology budget accounts for only about 14 percent of the DoD R&D budget.)

AAAS R&D Budget and Policy Program Director Kei Koizumi reported that because of the Bush Administration's goal of erasing the deficit and balancing the budget by 2012, the Federal R&D budget as whole, with the exception of budget related to the American Competitiveness Initiative (ACI), will be cut in FY 2008, as it was in FY 2007. In concrete terms, high priority is still given to target organizations in the ACI's second year, the U.S. Department of Energy Office of Science (DOE-OS), the National Science Foundation (NSF), and the National Institute of Standards and Technology (NIST) (laboratory portion), while the R&D budgets of other organizations remain the same or decrease. Even the National Institutes of Health (NIH) are down 1.2 percent. Furthermore, it is strikingly clear that while the basic and applied research budget is falling, the development budget is rising. Within the Federal R&D budget, basic research is down 0.2 percent ($28.2 billion), applied research is down 4 percent ($27.1 billion), but the development budget is up 2.9 percent ($82.8 billion). The increase in the DoD development budget has a major influence on this. (See Figures 1 and 2.)

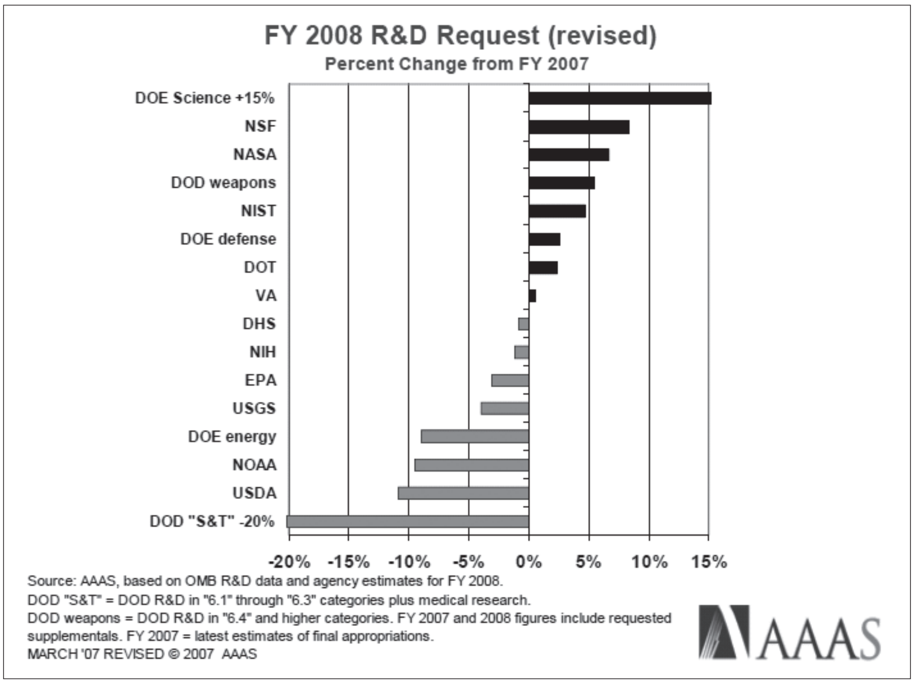


**Figure 1** : Percent change (from FY 2007) in FY 2008 R&D budget requests of various agencies

From Kei Koizumi, "Federal R&D Investments in the FY 2008 Budget"

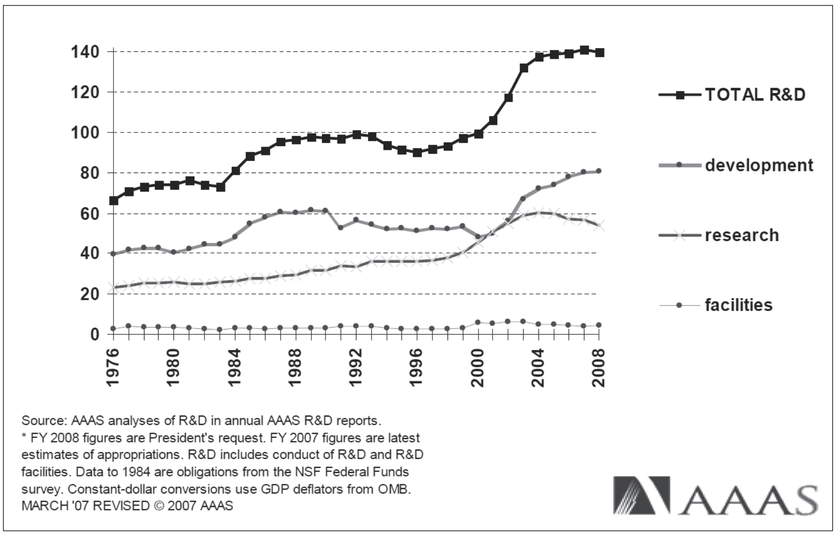


**Figure 2** : R&D budgets (FY 1976–2008)

From Kei Koizumi, "Federal R&D Investments in the FY 2008 Budget"

In addition, interest in climate change is rising, and even though President Bush's positive environmental policy, FY 2008 expenditures for the Climate Change Science Program (CCSP) are down 7.4 percent. According to Mr. Koizumi, this is because of the lower budget for NASA, which is the largest sponsor of climate change science.

## 3 Science and technology issues facing the USA

### 3-1 *Speech by John H. Marburger, Science Advisor to the President*

This was Mr. Marburger's sixth keynote address. He spoke about issues facing the US science and technology community and trends in the Federal R&D budget. His main points were as follows.

- **Diverse research funding sources and new business models required by universities**

The NIH's R&D budget doubled over the five years ending in FY 2003, bringing about an increase in the number of researchers. It will be difficult to maintain this rapidly expanded number of researchers using the conventional business model. Today, with competition for shares of the Federal budget intensifying, university research is beginning to diversify funding sources by turning to new business models such as building new relationships with private-sector sponsors. The Federal Government is encouraging such changes. Furthermore, future Federal R&D budgets are not expected to grow rapidly enough to meet the expanding scale of research. Further examination of mutual collaboration among Federal, state, and private funding is necessary.

- **Concern over and government action to mitigate the negative impacts of security measures**

As for the negative impacts of security measures on science since the 9/11 terrorist attacks, the situation regarding the issuing of student visas has greatly improved. However, serious issues remain, including the clumsy visa process for visiting scientists, implementation of an excessive export control regime, over-regulation of dual-use bioscience, and security measures at national laboratories that stifle user programs. At the same time, however, the government has formed numerous interagency committees to address the issues and seek solutions. For example, the National Science Advisory Board for Biosecurity (NSABB) formed in 2004 (in April 2007 it published a report entitled "Proposed Strategies for Minimizing the Potential Misuse of Life Sciences Research") is working on the problem of dual-use bioscience by examining guidelines on restricting the publication of scientific information that requires cautious handling. Furthermore, the Department of Commerce is also working on the problem of export regulations. The media should pay more attention to these efforts.

- **Efforts directed towards new science and technology benchmarks: a "science of science policy"**

In 2005 in this policy forum, I argued that the ratio of Federal R&D budget to GDP is not necessarily an effective indicator of a nation's science strength and that a new "science of science policy" with more quantitative benchmarks is necessary. In response, the NSF launched a "science of science policy" program inside the USA. I am also impressed by the fact that the OECD has taken up the discussion internationally[4].

- **Criticism of the AAAS budget analysis**

In the AAAS report on the FY 2008 Federal budget, there is an important failure in the treatment of earmarks*2. The report states that there would be steep cuts in the FY 2008 DoD science and technology (S&T) programs (20.1 percent from the previous year). (See Chart 1.) This report, however, does not accurately reflect recent debate on earmarks. It misinforms the readers of the AAAS report, which is widely used as an authoritative reference of the budget.

Last year in this policy forum as well, I pointed out that earmarks had rapidly increased during the past five years, to the point where it now threatens the missions of the agencies whose funds have been directed toward purpose that do not support the agency workplans. I urged the AAAS to work with the White House Office of Science and Technology (OSTP) and the White House Office of Management and Budget (OMB) to develop a mutually comprehensible approach to the problem of taking earmarks into account in analyzing the annual science budgets. Despite this, the AAAS has done nothing to correct its practice.

*Author's note: The reason the DoD science and technology (S&T) budget changed so much is because earmarks were removed based on the Bush Administration's earmarks reform. It is a mistake, however, to simply interpret that as a drastic cut in the DoD science and technology budget. There were many cases within the DoD earmarks of projects, such as diabetes research, that cannot be regarded as research that the DoD should be undertaking. Cutting such items does not necessarily mean that DoD's essential R&D budget was cut. Earmark reform is a course correction that cuts unnecessary earmarks and provides the relevant agencies with budgets for the important research that they should be doing. The gist of Mr. Marburger's criticism of the AAAS analysis is probably that this point was not sufficiently considered.

## 3-2 Issues in pharmaceutical and biotechnology R&D

One of the three plenary sessions at this year's forum covered "Pharmaceutical and Biotechnology R&D." This session included a description of the current situation and papers discussing problems in policy challenges for universities, corporations, and research institutes pertaining to productivity and innovation in pharmaceutical-related R&D, intellectual property rights and their effects on R&D, conflicts of interest in biomedical research and policy and ethical challenges in clinical trials. William Haseltine, Chairman of Haseltine Global Health LLC., gave an overview of the pharmaceutical industry, discussing the fact that the number of new drugs approved versus R&D investment has declined markedly. He blamed the stance of major corporations that are developing products for vast markets rather than with the aim of curing disease. He indicated that in corporations the ability to tie ideas to products is being interfered with.

Regarding the issue of productivity in the biomedical field, Scott Stern of Northwestern University pointed out the following paradoxes. (i) Despite enormous investment, the number of FDA approvals of drugs and biomedical agents is still about the same as in the 1980s[*3], (ii) despite the dramatic scientific progress of the last 30 years (from genetics to system biology), most therapies and treatments are based on older science and traditional technologies, (iii) although the biotechnology industry includes thousands of large and small companies, most therapies are commercialized by major pharmaceutical companies under the conventional FDA paradigm. Regarding experiments on rapidly developing tailor-made medicine, Mr. Stern pointed out that regulatory frameworks are not keeping pace and argued for the necessity of reforming the regulatory process[*3].

John M. Engel of the law firm Engel & Novitt discussed the important role played by intellectual property rights (IPRs) in promoting biomedical R&D. He emphasized that IPRs are becoming increasingly important in private-sector R&D because they are both an essential driving force for innovation that enables private-sector companies to obtain returns on their investments as well as effective safety nets that ease high risks.

In addition, Deborah A. Zarin of the National Library of Medicine discussed public policy and ethical problems in conducting clinical trials. Of more than 40,000 clinical trials today currently underway, 65 percent involve drugs. Many volunteers participate in trials sponsored by the pharmaceutical industry. However, trials may be oriented towards obtaining results rather than towards carrying out accurate scientific experiments, raising questions such as how to protect volunteers from improper risks, how to decide who has access to the results, and how to verify that the results are accurately assessed. Moreover, the results of most clinical trials go unpublished, and data that are published may be hard to find or contain errors. She pointed out that these are both ethical and scientific problems and argued that policy responses are necessary.

### *3-3 Sequestered science: (issues regarding concealing and revealing scientific information)*

The sequestering of scientific information, the question of whether all science and technology information should be published, was discussed from the perspectives of information sharing, disclosure, and management. Wendy Wagner of the University of Texas indicated that she thinks that while sequestering information for reasons such as protecting research progress or intellectual property, protecting privacy, or guarding from terrorist risks is not improper, disclosure is strongly required when risks to public health are involved, so guidelines that will function effectively in the real world are necessary. Myron Harrison, Senior Health Advisor at Exxon Mobil Corp., indicated that he believes that appropriate measures must be taken to ensure that confidential business information does not harm to the public's health. Furthermore, he used the example of the American Chemical Council's Long-range Research Initiative (LRI; research on the long-term effects of chemicals on human health and the environment), which has the right to release without permission any information regarding risks to the public discovered by LRI researchers. He stated that publishing all results is essential to improving the quality of research, and LRI is a good model of that. (Mr. Harrison defines "sequestered science" as "scientific results that are not readily available to the public.")

### *3-4 States' expanding roles in science and technology*

One of this year's concurrent session themes was "States' Expanding Roles in Science and Technology." Examples of actions by New Mexico, Pennsylvania, California, and Arizona were introduced, and the role of states in scientific and technological progress and the proper form for regional cooperation were discussed.

Thomas Bowles, Science Advisor to the Governor of New Mexico, indicated that his state is home to science and technology centers at several major Federal facilities, such as Los Alamos and Sandia National Laboratories, Phillips Laboratory, and White Sands Missile Range, with an annual R&D budget of $6 billion. He reported that the state has long-term R&D investment and incentive policies in its strong areas of aerospace, biology, energy, and IT, and works at the state level to promote innovation. He emphasized the significance of science and technology policy at the state level as an element driving innovation in New Mexico, saying, "We have the resources, but have lacked a plan and the commitment to make the necessary investments."

In addition, Susan Hackwood, Executive Director of the California Council on Science and Technology (CCST), described how the non-profit CCST provides valuable advice to the State Governor and the Federal Government. Modeled on the National Research Council (NRC), the CCST was founded in 1988. It collaborates widely with California universities, research institutes, and industry, engaging in a variety of initiatives to contribute to the state economy. Education is another of its primary activities. The CCST includes the California Teacher Advisory Council (Cal TAC), which establishes task forces to develop human resources in science and mathematics education. Ms. Hackwood also described trends and issues in science and technology in California.

In the USA, State Governments have developed science and technology strategies to improve science education, support innovation and to invest in R&D to ensure the development of the state economies. The role of State Governments in the development of science and technology in the states has therefore been significant. With the Federal R&D budget stagnating, the role of states is growing larger through efforts to promote further collaboration among regional industry and to prepare and improve environments supporting creativity and innovation. Furthermore, as can be seen in California's active efforts to tackle environmental issues, in some cases State Governments are proactively taking the place of the Federal Government in addressing global problems. This is a major change of direction.

### 3-5 Other themes

Other sessions took up the themes of "Building Science, Technology, and Innovation Capacity in Developing Nations" and "Surveillance, Privacy, and the Roles of Science and Technology."

The session on developing nations discussed cases such as the World Bank's program on building science, technology, and innovation capacity and initiatives in Latin America. In addition, Anny Wong of RAND gave an overview of the results of the Global Technology Revolution 2020[7]. This was a survey of global technology trends ranking the ability of 29 countries to acquire and implement 16 key technology applications.

The theme related to surveillance and privacy covered national security issues, which were a major topic in previous forums. This year's subjects for discussion were narrowed down to surveillance technologies and privacy and social issues. Content included discussion of trends in counterterrorism through information and privacy protection technology.

## 4 Conclusion

This year's policy forum was held amidst strong public interest in the actions of candidates in the coming presidential election and the haggling of President Bush and Congress surrounding the US military in Iraq. Attendees at the forum were most interested in responses to the trend of a declining Federal R&D budget. How to maintain and develop research activities when budgets related to defense development and ACI were being given a high priority while the R&D budgets of other organizations were static or declining was a common subject in the discussions in various the sessions on the role of states in science, problems facing the pharmaceutical industry, and so on.

This year's forum did not hold a special session to discuss environmental issues, in which there was growing interest in Japan after President Bush announced the goal of cutting gasoline use 20 percent over the next 10 years in his January 2007 State of the Union Address and showed signs of aggressively addressing climate change. However, clean energy was one of the themes discussed in last year's forum, and on April 28 the AAAS Board of Directors released a statement on their sense of crisis regarding climate change and distributed it at the forum. The AAAS thus indicated that it still has a strong interest in environmental issues[8].

By bringing key people in science and technology policy, such as Presidential Science Advisor Marburger to meet with the entire scientific community, the AAAS forum plays a historically significant role. It is likely to continue to play this role in the future. It will remain very meaningful to continue Japanese participation in these important policy discussions as a way of gaining an understanding of the major issues related to US science and technology policy.

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**Glossary**

*1 The AAAS is the world's largest non-profit organization for scientists, engineers, science educators, policymakers, and so on, with over 140,000 members. It is well-known as the publisher of the journal Science.

*2 Earmarks differ from competitively selected funds in that they are selected by debate over their intended use. They have increased rapidly in the past few years and are widely used to bring pork-barrel funds to the districts of members of Congress. The lack of transparency in the process and the way they can interfere with funding mechanisms for important research are seen as problems within the Administration. In his January 2007 State of the Union Address, President Bush proposed comprehensive reform to make the earmark process transparent and accountable through steps such as making all earmark information available to Congress and cutting earmark funding in half[5]. The funding resolution passed in February 2007 included a moratorium on earmarks that temporarily froze all earmarks. As part of the reform, all future earmarks will probably be more carefully selected. According to the OMB, which is building a database on earmarks, in FY 2005 alone, they numbered 13,497 for over $19 billion. The DoD accounted for more than half that number.

*3 The report “Innovation or Stagnation: Challenge and Opportunity on the Critical Path to New Medical Products” released by the US Food and Drug Administration (FDA) in March 2004 pointed out similar issues[6]. It indicated that the number of applications for approval of new drugs has fallen dramatically in recent years, and that despite the expectations of the biomedical revolution, new scientific discoveries are not being converted to the development of safe and effective drugs. As causes, the report cites today’s more challenging, inefficient, and expensive drug development path, along with the failure of the applied science required for drug development to keep pace with the marvelous progress of basic science. The report states that new scientific and technical methods such as animal or computer-based predictive models, biomarkers for safety and effectiveness, and new clinical evaluation techniques -- are urgently needed to improve predictability and efficiency along the critical path from laboratory concept to commercial product.

**References**


[1] For information on past forums, see: “Science and Technology Trends in the United States: Report on the AAAS Annual Forum on Science and Technology Policy,” Science and Technology Trends-Quarterly Review, No. 13, October 2004 and “Report on the Annual AAAS Forum on Science and Technology Policy,” Science and Technology Trends- Quarterly Review, No. 21, October 2006: http://www.nistep.go.jp/achiev/ftx/jpn/stfc/stt038j/0405_03_feature_articles/200405_fa04/200405_fa04.html, http://www.nistep.go.jp/achiev/ftx/jpn/stfc/stt063j/0606_03_featurearticles/0606fa03/200606_fa03.html

[2] For the forum program and materials presented, see the 32nd Annual AAAS Forum on Science and Technology Policy website: http://www.aaas.org/spp/rd/forum.htm.

[3] See “A Preview of AAAS Report XXXII: Research and Development FY 2008”: http://www.aaas.org/spp/rd/prev08p.htm.

[4] Regarding OECD initiatives, see the report on the “Workshop on Science of Science Policy: Developing our Understanding of Public Investments in Science” in the August 2006 NISTEP News (Japanese): http://www.nistep.go.jp/NISTEP_News/news214/news214.html

[5] State of the Union 2007: http://www.whitehouse.gov/stateoftheunion/2007/index.html

[6] http://www.fda.gov/oc/initiatives/criticalpath/whitepaper.html#execsummary

[7] For the full report, see: http://www.rand.org/pubs/technical_reports/TR303/.

[8] “AAAS Board Statement on The Crisis in Earth Observation from Space,” 28 April 2007 quotes the National Research Council (NRC) report “Earth Science and Applications from Space” (2007), which

states that "the United States' extraordinary foundation of global observations is at great risk" by 2010 and warns of major data gaps if cuts in funding for global observation satellite related funding continue:
http://www.aaas.org/news/releases/2007/media/aaas_board_eos_statement.pdf

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# About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organizations, with MEXT and other ministries under the general supervision of the Council for Science and Technology Policy, Cabinet Office (CSTP), to develop strategic science and technology policy.

NISTEP has established the Science and Technology Foresight Center (STFC) with the aim to strengthen survey functions about trends of important science and technology field. The mission is to provide timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

Beneath the Director are six units, each of which conducts surveys of trends in their respective science and technology fields. STFC conducts surveys and analyses from a broad range of perspectives, including the future outlook for society.

The research results will form a basic reference database for MEXT, CSTP, and other ministries. STFC makes them widely available to private companies, organizations outside the administrative departments, mass media, etc. on NISTEP website.

**The following are major activities:**

## 1. Collection and analysis of information on science and technology trends through expert network

— STFC builds an information network linking about 2000 experts of various science and technology fields in the industrial, academic and government sectors. They are in the front line or have advanced knowledge in their fields.

— Through the network, STFC collects information in various science and technology fields via the Internet, analyzes trends both in Japan and overseas, identifies important R&D activities, and prospects the future directions. STFC also collects information on its own terms from vast resources.

— Collected information is regularly reported to MEXT and CSTP. Furthermore, STFC compiles the chief points of this information as topics for "Science and Technology Trends" (monthly report).

## 2. Research into trends in major science and technology fields

— Targeting the vital subjects for science and technology progress, STFC analyzes its trends deeply, and helps administrative departments formulate science and technology policies.

— The research results are published as articles for "Science Technology Trends" (monthly report).

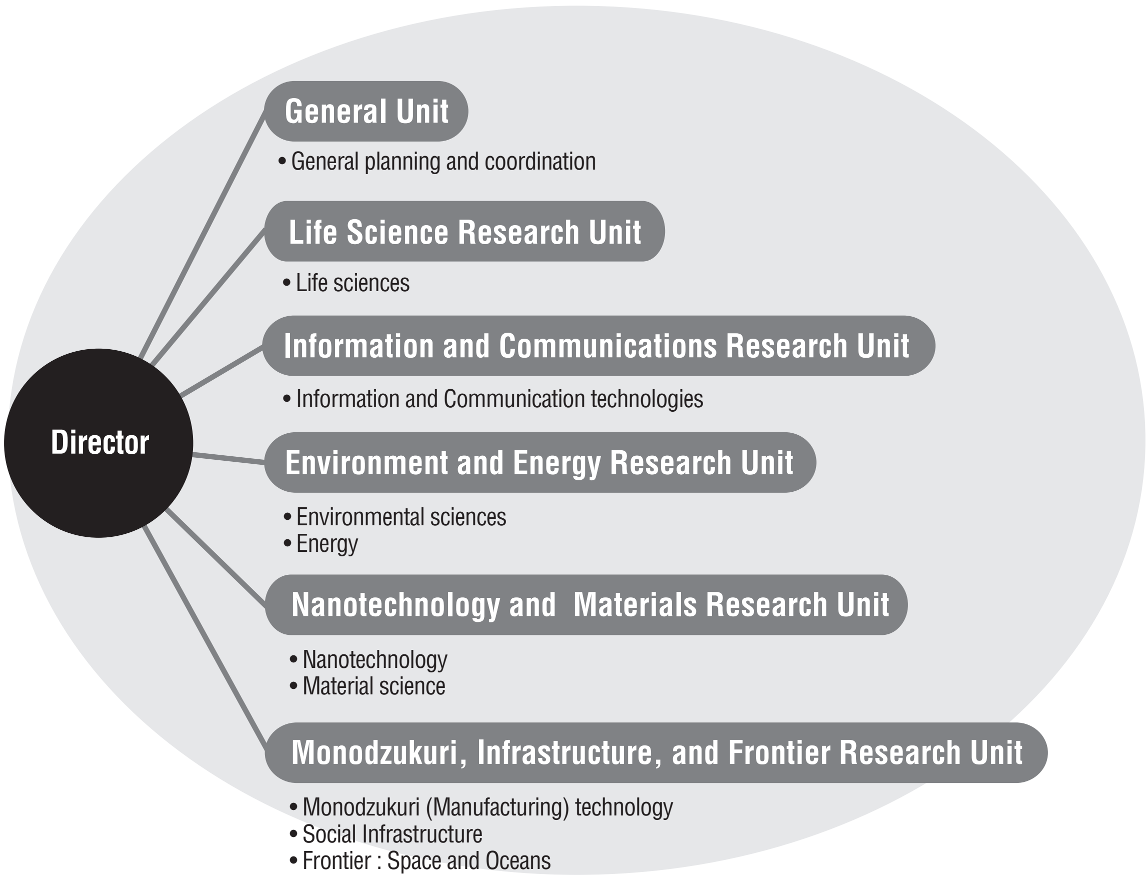
## 3. S&T foresight and benchmarking

— S&T foresight is conducted every five years to grasp the direction of technological development in coming 30 years with the cooperation of experts in various fields.

— International Benchmarking of Japan's science and engineering research is also implemented periodically.

— The research results are published as NISTEP report.

**Organization of the Science and Technology Foresight Center**

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